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# SILVICULTURE OF SHORTLEAF PINE

(First of a Series on the Silviculture of Southern Forests)

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and

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NACOGDOCHES, TEXAS

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Sponsored by the Conservation Foundation

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NACOGDOCHES, TEXAS

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# PREFACE

Nowhere is silviculture more intensively practiced than in the southern United States except, perhaps, in certain European nations. This is because of the tremendous demands upon the forests for fiber in a region of optimum climatic characteristics for rapid growth of valuable species. In meeting these demands, management instructs its foresters to shift their efforts into high gear.

Such efforts frequently necessitate operations not completely understood from the biological viewpoint. Foresters, like other professional people, study technical journals in off hours, and the number of these in which a man is sufficiently mentally alert after long hours in the field is quite limited. As research information is released at an ever-increasing pace, making careful scrutiny of literature impossible, it is difficult to keep abreast. The rapidly expanding jargon of the researcher in the several specialized fields and the nonavailability of technical releases in remote stations also widen the gap between practice and knowledge. In spite of these handicaps, many foresters are well-versed in the biology of silviculture.

Yet serious deficiencies exist. This the senior author noted during a one-year assignment for the National Plant Food Institute which enabled him to visit virtually every forest research group and a host of forest management operations from central Texas to the coast of Virginia and the Carolinas.

This is the first of a series of bulletins planned to present the silviculture of southern tree species. This series is intended to aid foresters in the field—to bring together the latest information from across the South, believing that knowledge gained from trials in the eastern part of the region has something to offer foresters in the western sector. Then, too, it is hoped these pages will provide some understanding as to why, biologically, silviculture practices are suggested.

Our interest here is relating science to practice. To do so, phases of plant physiology, ecology, and soils are incorporated. Economics, however, is generally omitted, although it obviously can not be ignored in practice. Facts and philosophy are presented, but the practitioner will need to decide for his situation the value of a suggested technique. The material is prepared especially for practicing foresters, but it is also anticipated that the faculties in the fifteen schools of forestry in the South may find it stimulating for classroom use.

Research men have really written this publication. We have done the "read search," merely compiled from their reports. Many have reviewed various portions of the manuscript, and their assistance is gratefully acknowledged.

L.C.W.
H.V.W.

Nacogdoches, Texas

# SILVICULTURE OF SHORTLEAF PINE[1, 2]

Shortleaf pine[3] occurs with loblolly pine throughout most of the upper Coastal Plain of the mid-South and Southeast. It is found infrequently with other southern pines where these are predominant in the lower Coastal Plain, and it may occur pure in the Coastal Plain if other pine seed sources are lacking. In Maryland and Delaware, shortleaf pine forests are often pure, may occur with Virginia pine, and suffer encroachment of hardwoods. In the Piedmont province, shortleaf pine, alone or with loblolly pine, initiates tree invasion of old-fields. The shortleaf pine-Virginia pine and shortleaf pine-pitch pine types occur on dry sites of southern slopes and old-fields in southern New Jersey. Either in pure stands, or mixed with other pines, the types are even-aged.

## Sites

There is no typical site for shortleaf pine. Like most forest trees, it grows best on moist, but well-drained, or mesic, sites. On these better sites, often coves of limited area, growth may exceed that of loblolly pine, but form is usually inferior to that of loblolly pine. Exceptions to this generality occur in southern Arkansas (Grano, 1956) and among certain Texas strains.

In the Missouri Ozarks, stony loam soils derived from Roubidoux sandstone, especially on well-dissected terrain, support extensive stands of shortleaf pine, as other species are unable to compete. Poor soil moisture on south- and west-facing slopes further encourages shortleaf pines over many other species; shortleaf pine is less drought resistant than eastern redcedar, about the same as white oak, and more resistant than black, southern red, and scarlet oaks.[4] Shortleaf pine usually occurs on south slopes in the Arkansas Ozarks, where it is adapted to deep, cherty, silt loam soils underlain by Boone chert and limestone. The species is also suitable for (1) moderately deep sandy clay underlain by Joachim sandy limestone, (2) shallow, poorly drained sandy clay derived from Newton sandstone, or (3) deep loamy sands (Read, 1950).

## Succession

Shortleaf pine invasion in the Piedmont is not conditioned by, nor directly related to, succession of herbaceous plants, but, rather, by chance coincidence of good seed years and favorable weather for germination every 3 to 5 years. Seldom is the coincidence less frequent than every 10 years (McQuilkin, 1940). The condition of the seed-bed at time of seed dissemination is of equal importance.

Structure and development of old-field stands is associated with soil physical properties. In the North Carolina Piedmont province, Billings

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[1] Silvicultural similarities of shortleaf and loblolly pines include rotation ages, thinning, pruning, planting, and practices for reproduction cuttings. This bulletin presents data applicable specifically for shortleaf pine; a later publication will report techniques for shortleaf pine when associated with loblolly pine.

[2] A bibliography covering the literature pertaining to this species from about 1900 to December, 1960, has been compiled by Haney (1962a).

[3] The scientific names of species mentioned are given in the *Appendix*.

[4] See Fletcher and McDermott (1957) on the influence of geologic parent material and climate on shortleaf pine distribution in Missouri.

(1938) found the rate of oak invasion among pines related to the thickness of the organic horizon, water-holding capacity, volume-weight, organic matter percent, and the moisture equivalent of the soil. Hardwoods enter succession more rapidly under favorable conditions. Between 20 and 30 years after pines seed in, the brown plow zone grows thinner and is replaced by a blackish-gray A1 horizon. The soil volume-weight decreases and water-holding capacity rises with related increases in moisture equivalent values and organic matter content. As depth of *L*, *F*, and *H* layers increases with the closing of the canopy and exclusion of light from the forest floor, herbaceous cover decreases.

Oaks enter succession at about age 20, when enough litter has collected to protect the soil from desiccation and to make the surface porous. Hickories follow in 10 years. During this time, newly-germinated pines live less than a year, and after age 50, very few pine seeds germinate. Eventually, a white oak-black oak-red oak type develops. In the North Carolina Piedmont, released maples become dominant following conifer harvests; but where not released, oaks suppress maples. Yellow-poplar joins red maple as a codominant in the mixed deciduous forests replacing pine. Eastern redcedar, persimmon, and dogwood persist in the understory.

## GROWTH

### Seasonal Growth

Shortleaf pine is a multinodal species, and its seasonal pattern of terminal growth is expressed in several surges variously related to one another (Tepper, 1963). Growth of shortleaf pine in the Georgia Piedmont begins in early April, when new shoots begin to elongate; half of the annual increment is attained within 80 days or by mid-June. Jackson (1951) determined the "grand" period of growth—the number of days required for 5 to 95 percent of total seasonal growth—to be about 170 days. In dendrometer measurements of growth, no consistency was found between starting date of spring growth and rapidity of growth, nor did periodic spurts in radial growth coincide with renewed terminal flushes of growth. Radial growth, slowing down during midsummer if soil moisture is depleted, is concluded in October (Jackson, 1952; Kramer, 1943). Diameter growth begins about the same time as height growth (Boggess, 1956).

Greatest diameter increment for an 18-inch shortleaf pine in the Appalachians occurred in the spring, regardless of the amount of spring rain. But with soil moisture depletion in early summer, daily growth was one-half that of spring increment and trees shrank from desiccation. Summer rains, however, promptly stimulated growth through mid-August (Bryam and Doolittle, 1950). For north Mississippi well-stocked stands, diameter growth was added only during the first one-third to one-half of the 7-month-long growing season (McClurkin, 1961). In the mid-South, height growth of shortleaf pine seedlings is about 85 percent complete by early July and 95 percent complete by the first of August.

### Volume Growth

Growth of shortleaf pine in normal stands on SI 70 (SI=site index at 50 years) land is about 80 board feet annually for 30-year-old forests and 400 board feet for stands 60 years old. Yields at 60 years approach 24 MBM. For SI 90, annual growth is 370 board feet for 30-year-old stands and 640 board feet for forests 60 years old. Yields at age 60 on these good sites approximate 40 MBM (Forbes, 1955).

On an eroded Piedmont site, average dbh for shortleaf pine is 16 percent under that for loblolly pine at age 14. Apparently, shortleaf pine suffers more in terms of growth from competition of close spacing than does loblolly pine (Jackson, 1958). This is compensated for by the better ability of shortleaf pine to endure dense stocking. At present, however, many sites are producing less than 60 board feet per acre per year.

On better soils of the Ozark region, the potential for timber production is more than 400 board feet per acre per year for shortleaf pine, slightly more than the productive capacity of the finest hardwoods and several times that of eastern redcedar (Koen, 1948; Maple and Mesavage, 1958). For an old-field of medium productivity—SI 70—with a 90-year-old stand of 34 MBM per acre, mean annual growth was 425 board feet per acre. Basal area was 150 square feet per acre and the mean tree was 13 inches dbh. The site is a sandy loam 10 inches deep underlain by 2 feet of semi-plastic clay loam.

### Virgin—Second-Growth Relations

A comparison of virgin and second-growth shortleaf pine indicated that virgin stems have twice as much heartwood, fewer and smaller knots, and finer grain, while second-growth has sounder and tighter knots and fewer pitch defects (Davis, 1931). It might be reasoned, then, that for lumber production second-growth should be grown to larger sizes to get more heartwood and better grade yield, pruned to maintain tight knots, and stand density controlled to form fine-grained wood.

### Site Index

#### Eastern Zone

Shortleaf pine site index seldom equals that of loblolly pine, even on the best sites—those with 8 inches or more of topsoil overlaying friable or very friable subsoil. Usually shortleaf pine is 10 to 15 units below loblolly pine because, perhaps, the feeding roots of the former are most abundant in the upper few inches of soil, while loblolly pine roots are larger in size and more deeply distributed, although fewer in number (Copeland, 1952). Hence, when the wilting percentage is reached, fibrous roots of shortleaf pine in the surface soil succumb early. Olson and Della-Bianca (1959) also noted that shortleaf pine has lower site indexes than any of its associated species in the Piedmont. Average shortleaf pine site index for North Carolina is 59 (Larson, 1957). It differs little between Coastal Plain and Piedmont stands, both usually ranging between 50 and 70 (Cruikshank, 1954).

Surface soil depth and consistency of subsoil are related to the availability of soil moisture and drainage characteristics. Both are also related to the amount of space available for root growth. Thus, for the Piedmont province, Coile (1952) showed a relationship of site index to subsoil

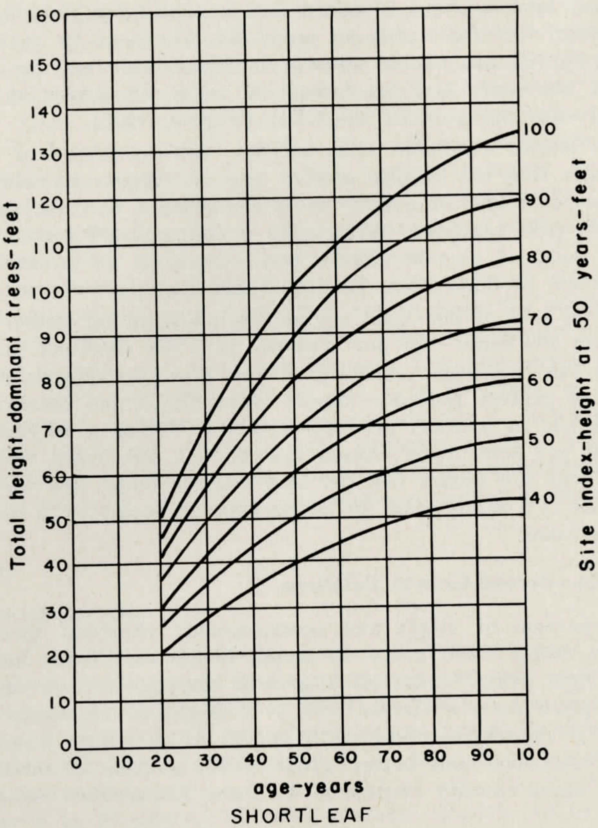



**Figure 1—Site index curves for shortleaf pine (from Anonymous, 1929).**

consistence and depth to subsoil—site index increasing with depth but decreasing with greater plasticity (Table 1). This relation is shown by the equation

$$SI = 77.32 - \frac{45}{X} - 1.00Y,$$

where X = depth of surface soil in inches,
and Y = imbibitional water value of subsoil
(Coile and Schumacher, 1953a).

The equation is further refined thus:

$$\log SI = 1.8878 - \frac{0.1580}{X} - 0.00859\ (Y) - \frac{0.0408}{Y} + 0.0053\ (Z)$$

where X = depth of surface soil in inches,
Y = imbibitional water value of subsoil,
and Z = +1 for northern portion of shortleaf pine range,
or
—1 for southern portion of shortleaf pine range.
(Cruikshank (1954) found little difference in site index by latitude.)

For certain sandy loams and sandy clay loams of the Piedmont, Coile (1953) found $SI = \frac{\text{silt} + \text{clay content, in \% of B1.}}{\text{average depth to B1 in inches}}$

TABLE 1. SITE INDEX VALUES FOR SHORTLEAF PINE IN THE PIEDMONT PLATEAU ARE INFLUENCED BY SOIL (after Coile, 1952).

| Subsoil consistence | Depth to subsoil (inches) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 4 | 6 | 8 | 10 | 12 | 18 |
| | Site index | | | | | | |
| Very friable | 51 | 62 | 66 | 68 | 69 | 70 | 71 |
| Friable | 47 | 59 | 62 | 64 | 65 | 66 | 67 |
| Semi-plastic | 43 | 54 | 58 | 60 | 61 | 62 | 63 |
| Plastic | 38 | 49 | 53 | 55 | 56 | 57 | 58 |
| Very plastic | 33 | 44 | 48 | 50 | 51 | 52 | 53 |

For young stands, Coile and Schumacher's (1953) curves are used because site indexes as high as 110 to 120 for stands 15 to 20 years old, estimated from the standard curves (Fig. 1), do not exist (Fig. 2).

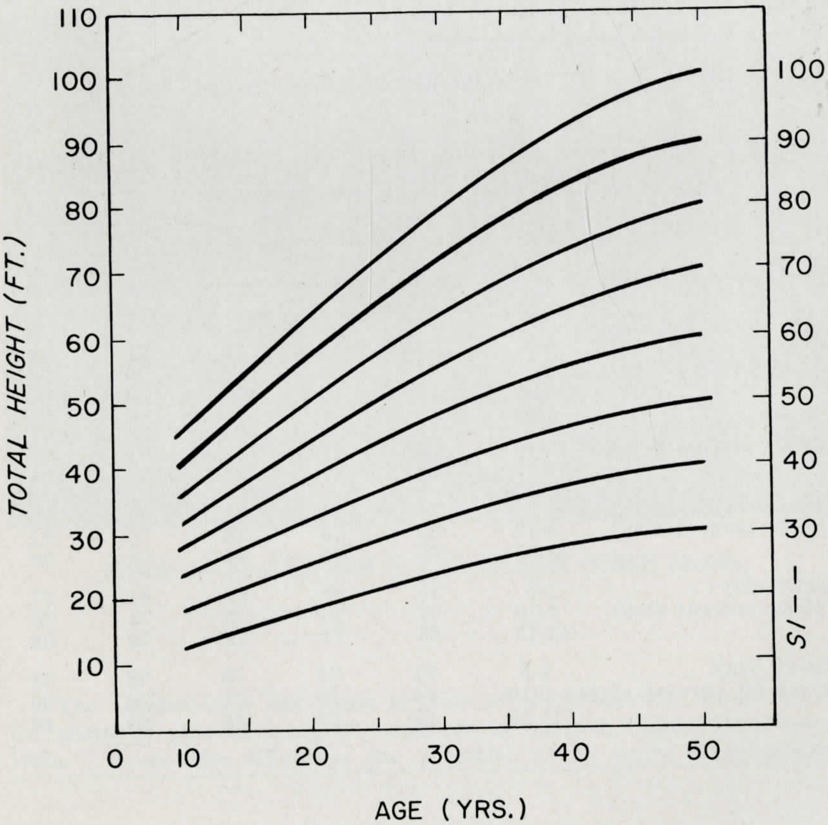



**Figure 2—Site index curves for young shortleaf pine stands in the Piedmont province (from Coile and Schumacher, 1953).**

The relation of dbh to tree age for particular site indexes enables the determination of the number of years required to grow trees to specific sizes in evenaged stands. Thus, to reach 10 inches dbh, dominants and codominants in North Carolina require:

50 years on areas of SI 50
43 years on areas of SI 60
37 years on areas of SI 70
32 years on areas of SI 80 (Larson, 1957).

**Western Zone**

Site index ranges from about 45 to 90 in the Coastal Plain (Turner, 1936a; Dean and Case, 1959). It is optimum in southern Arkansas on zonal upland soils with sandy clay loam and clay loam subsoil under 18 inches of surface soil and where slopes do not exceed 5 percent (Fig. 3). Growth potential decreases as surface soils become shallower or deeper, as subsoils change to finer and coarser textures, and with increasing slope (Table 2, Figure 4). Although not commonly associated with loblolly pine on azonal soils, where shortleaf pine is prevalent, the following relation between the two species is expressed:

$$SI = 13 + 0.77 \text{ (SI for loblolly pine)}$$ (Zahner, 1957).

TABLE 2. SITE INDEX OF SHORTLEAF PINE ON ZONAL UPLAND SOILS (from Zahner, 1957).

| | | Thickness of surface soil | | | | |
|---|---|---|---|---|---|---|
| Textural grade of subsoil | Slope class | 6 inches | 12 inches | 18 inches | 24 inches | 30 inches |
| | Percent | | | Site index | | |
| Loam | 1-5 | 71 | 76 | 78 | 77 | 74 |
| (10-20 percent clay) | 6-10 | 64 | 69 | 71 | 70 | 66 |
| | 11-15 | 62 | 67 | 69 | 69 | 65 |
| Sandy clay loam | 1-5 | 75 | 80 | 82 | 81 | 77 |
| (20-30 percent clay) | 6-10 | 67 | 72 | 75 | 74 | 70 |
| | 11-15 | 66 | 71 | 73 | 72 | 68 |
| Clay loam | 1-5 | 76 | 81 | 83 | 82 | 78 |
| (30-40 percent clay) | 6-10 | 69 | 74 | 76 | 75 | 71 |
| | 11-15 | 67 | 72 | 74 | 74 | 70 |
| Light clay | 1-5 | 75 | 80 | 82 | 81 | 77 |
| (40-50 percent clay) | 6-10 | 67 | 73 | 75 | 74 | 70 |
| | 11-15 | 66 | 71 | 73 | 72 | 68 |
| Heavy clay | 1-5 | 71 | 76 | 78 | 78 | 74 |
| (Over 50 percent clay) | 6-10 | 64 | 69 | 71 | 70 | 66 |
| | 11-15 | 62 | 67 | 70 | 69 | 65 |

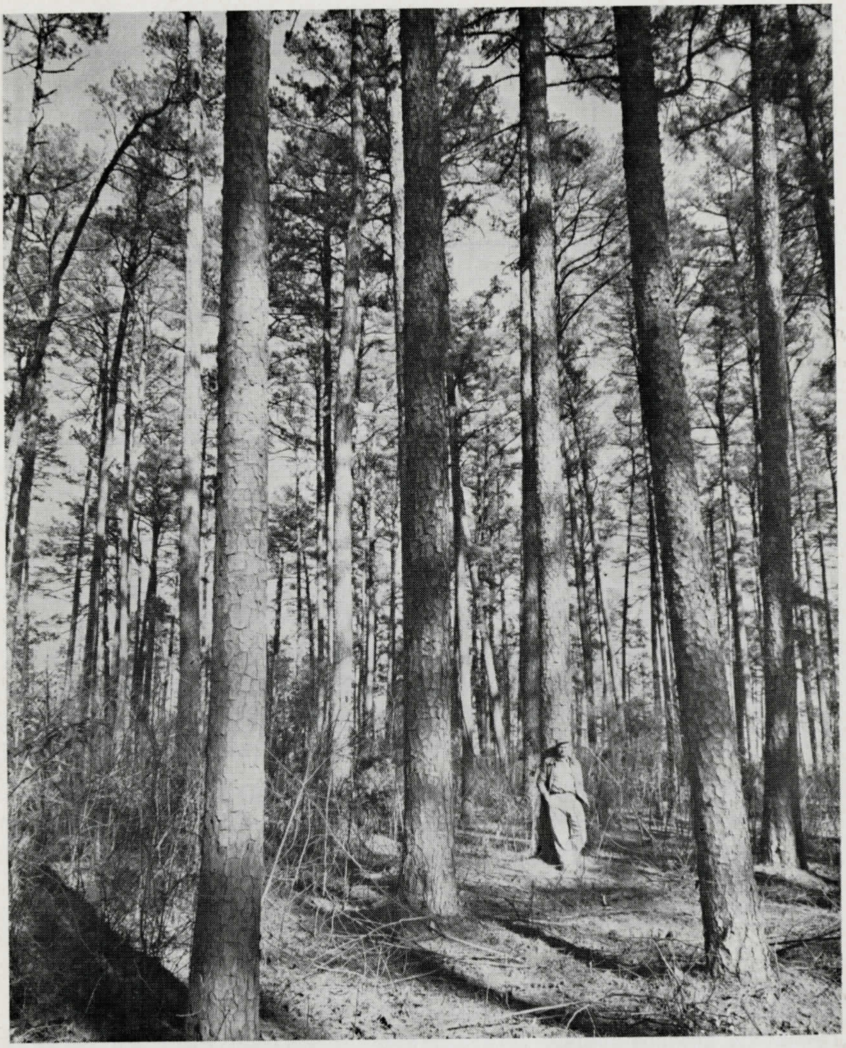


**Figure 3—Shortleaf pine in the mid-south (USFS photo).**

The statistically significant relation of height growth to soil series for shortleaf pine in southern Arkansas is unusual (Table 3) (Turner, 1936a ). Slope also influences site potential within series classifications.

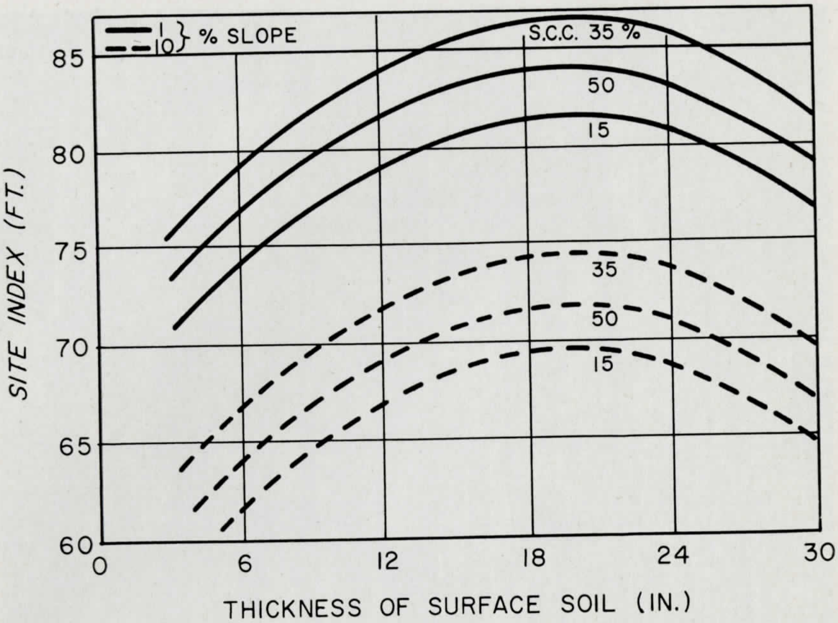



**Figure 4—Shortleaf pine site index on zonal soils, as related to thickness of the surface soil, slope, and subsoil clay content (scc) for the southern Arkansas area (from Zahner, 1957).**

TABLE 3. AVERAGE SITE INDEXES OF SHORTLEAF PINE ON SOILS OF SOUTHERN ARKANSAS (after Turner, 1936a).

| Soil series and type | Slope | Site index |
|---|---|---|
| | Percent | |
| Caddo silt loam | 2 | 90 |
| Caddo very fine sandy loam | 3 | 78 |
| Caddo-Ruston transition | 2 | 89 |
| Greenville gravelly loam | 10 | 70 |
| Hanceville fine sandy loam (plateau) | 5 | 80 |
| Hanceville fine sandy loam (gully) | 5 | 65 |
| Hanceville fine sandy loam | 7 | 65 |
| Hanceville fine sandy loam | 13 | 53 |
| Hanceville fine sandy loam | 25 | 45 |
| Norfolk fine sandy loam | 2 | 68 |
| Ocklockonee sandy loam | 1 | 92 |
| Ruston fine sandy loam | 2 | 83 |
| Ruston fine sandy loam | 6 | 72 |
| Susquehanna fine sandy loam | 4 | 75 |
| Susquehanna fine sandy loam | 9 | 73 |

Turner's (1937a) descriptions of site classes for loblolly pine are applicable with the following qualifications:

Site Index
for Loblolly Pine
110: shortleaf pine is not adapted to silt loam types; sandy loam types have SI 90 for shortleaf pine.
100: shortleaf pine generally absent.
90: also 90 for shortleaf pine.
80: also 80 for shortleaf pine.
70: shortleaf is frequently the only pine present.
60: shortleaf is frequently the only pine present.

In East Texas, alluvial bottomlands of fine sandy loam with 10 to 20 inches of well-drained surface soil and mottled subsoil have SI 100. In upland fine sandy loam and fine sand, soils with good internal drainage, SI is about 74. Heavy **B** horizons within 15 inches of the surface results in poor growth and site index of about 68. Sandy soils more than 10 inches deep and with water tables beyond reach of tree roots have SI 60 (Chandler, Schoen, and Anderson, 1943).

In the northwestern extremity of the species range, 72 percent of the site quality variation is associated with differences in (1) thickness of **A** horizon in inches (A), and (2) percentage of clay in the **A** horizon (B), according to the equation:

$$\text{Mean annual height growth in feet} = 1.05 + 0.0192(A) + 0.0157(B).$$

From this, average yearly height growth can be predicted within 0.14 feet two out of three times (Dingle and Burns, 1954).

For the Ozark highlands, site indexes range from 27 to 65; for the Ouachita highlands to the south, they are between 30 and 67 (Ray and Lawson, 1955). For both areas, soil types influence site index.

Some soils, especially sandy loams, when subjected to severe erosion have site index decreased by as much as 30 points (Kittredge, 1952). Clay loams and clays may be reduced up to 15 units.

Series characterized by loose surface soils but with cemented hardpans deserve pointed attention. This condition often results in high site potential estimates from early observations of plantations. But when soil moisture is depleted in the shallow profile and capillary sources of water are exhausted, site quality is sharply diminished. The hardpan also prevents tap root elongation. Survival in plantations on such sites is poor, as root penetration for establishment is favored by light, sandy soils.

### Soil Moisture

Shortleaf pine, although sensitive to soil moisture, survives on xeric as well as hydric sites. Yet, available soil water is the most important variable influencing its survival and growth.

Shortleaf pine may be rather drought resistant because of its capacity to (1) absorb water when soil moisture is limited, (2) hold water in its leaves under drought conditions, and (3) maintain high solute concentrations when recovering from drought. Schopmeyer (1939) discounted the theory that trees conserve water by retarding transpiration or chemically tying up water within certain organs.

Precipitation appears to control the range of shortleaf pines, the 17-inch isohyet of winter precipitation (November to April) defining its northwestern extremity and suggesting the necessity of adequate winter moisture for survival and growth (Fletcher and McDermott, 1957). However, in Virginia, growth depends upon total precipitation, but not its seasonal distribution (Schumacher and Day, 1939).

The amount of rain affects height growth more than it does the length of the growing season. Seedlings were ½ foot taller in a year of 135 percent of normal rainfall than in one of 73 percent normal in the mid-South. However, because that favorable season followed the year of low rainfall by 2 years, the natural increase in vigor with age may have contributed to this response (Williston, 1951). Available water at the 2- to 3-inch soil depth during the period of maximum height growth is greatly influenced by evaporation and transpiration. For open fields in the Piedmont it was 8 percent, and for light and heavily cut stands, 10 and 12 percent. Increasing available water by site preparation could be important, as the weight of shortleaf pine seedlings increases linearly with 3 to 20 percent available moisture in a Piedmont forest soil (Ferrell, 1953). In the Ouachita province of Arkansas, a relationship was found between latewood growth and late summer precipitation (Schulman, 1942).

Total evapo-transpiration losses from stands in the New Jersey Barrens for the growing season is about 20 to 22 inches, in contrast to 17 inches from bare soil. Thirty percent of the moisture removed is from the top foot, 22 percent from the second foot, and 16 percent from each of the next 3 feet. Evapo-transpiration from 7-year-old pine seedling-oak sprout stands is governed largely by transpiration of sprouts which remove water as rapidly and to the same depth as older oak stands (Lull and Axley, 1958).

Boggess (1956) observed that when moisture storage capacity of the profile is limited by depth or a hardpan, frequent rains throughout the growing season are necessary for sustained growth. Three weeks without rain in summer may exhaust available water between the surface and the hardpan.

Upon artificially inducing drought in a 35-year-old shortleaf pine stand in a Piedmont sandy loam soil, (1) branches died from the bottom upward, (2) needle length was reduced from 3½ inches to 1 inch, (3) needle retention on twigs was reduced from 7 to 3 inches from buds, leaving crowns thin and tufted, (4) needle color was not affected, (5) after 5 years, the crown was sparse and about one-half of the original size, death of branches proceeding upward from the crown base, and (6) after 5 years, growth almost ceased (Copeland, 1955). Nitrogen in foliage of drought-induced trees was normal. This is in contrast to deficiencies of nitrogen in trees with littleleaf disease, supporting the theory

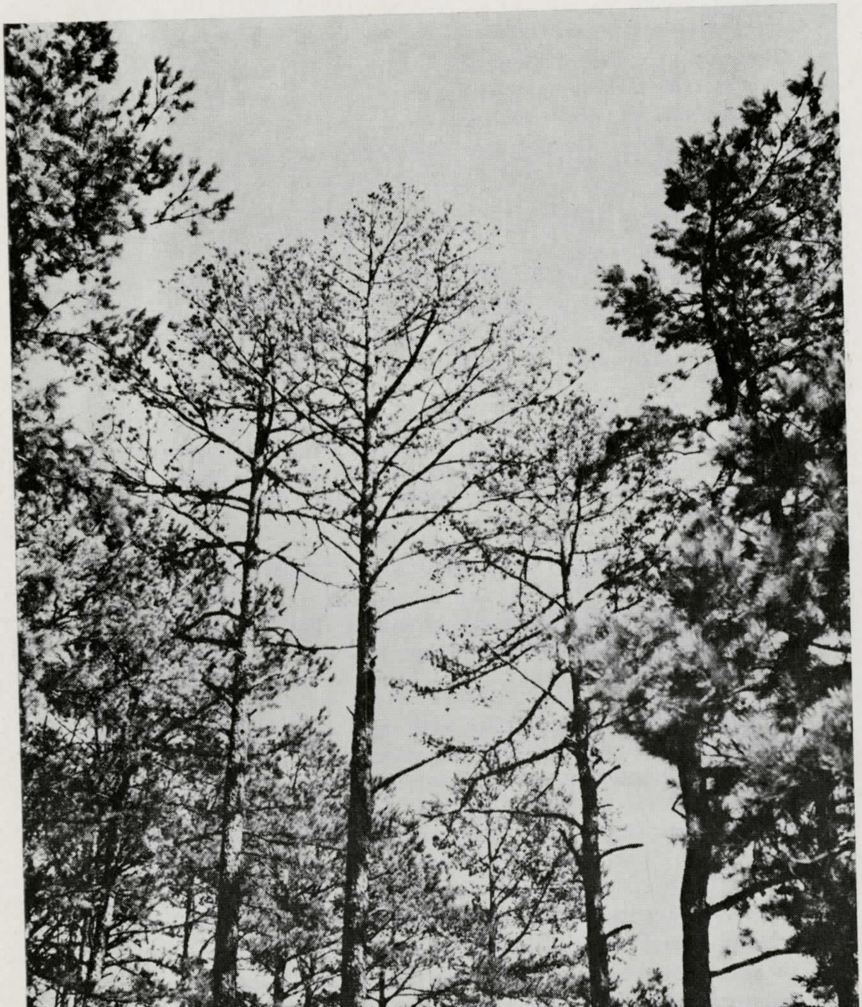


Figure 5—Trees subjected to prolonged artificially induced drought, showing numerous dead lower branches and tufted sparse crowns. Healthy shortleaf pines are adjacent to the treated plot (from Copeland, 1955).

that drought does not cause the malady, but there was less foliage for dilution of total element content on treated trees.

**Roots**

Trenching studies of shortleaf pine rooting habits in a Coastal Plain silt loam soil showed virtually all of the root cross-section area in the upper 18 inches, due to poor drainage and poor aeration at lower levels. Subsoils with good aeration and drainage, such as a sandy loam, have about 90 percent of the root cross-section area in the upper 18 inches. This small difference in cross-section under critical conditions could be important for moisture and nutrient absorption. The number of roots, too, is greatest in the upper 9 inches of a fine sandy loam soil. Beginning with 155 roots less than ¼ inch diameter in a trench face 4 feet wide, the number decreases by one-half with each 9-inch descent. Shortleaf pine roots penetrate plastic clay, but branching of roots is poor in contrast to friable soils (Turner, 1936).

In pure pine stands and at various stages of succession in the Piedmont, most pine roots lie near the surface. Sixty percent of them are in the upper 6 inches and 80 percent in the upper foot of soil. Hardwood roots, on the other hand, extend deeper than pine roots (Billings, 1938).

In the South Jersey pine Barrens of sand and fine sandy soils, water use by shortleaf pine and scrub oak is about the same from the upper 5 feet during the growing season. Both remove moisture from as low as 12 feet, the water moving upward by capillarity to within reach of active roots.

Utilizing 1-year-old seedlings with air, nutrition, and moisture controlled, Zak (1961) showed that shortleaf pine developed a larger root system with a greater mass of mycorrhizae than did loblolly pine, while the latter showed greater tolerance to poor soil aeration. (Several species of mycorrhizal fungi are associated with these pines (Bryan and Zak, 1962; Zak and Bryan, 1963).) These observations, and the low soil moisture demand of shortleaf pine, may explain its prevalence on dry, well-drained sites of low fertility in the Piedmont. Although this species only rarely invades areas with high water tables, seedlings are able to withstand continuous flooding for long periods. After 12 weeks, even stagnant water had only a slightly detrimental effect on growth and no influence on survival in greenhouse tests of non-dormant trees (Hunt, 1951).

McQuilkin (1935) reported shortleaf pine tap roots in the Barrens are larger than pitch pine roots. Secondary roots, in contrast, are more weakly developed.

During periods of drought, roots are suberized with material impermeable to water; but moisture continues to enter, apparently through lenticels, breaks around branch roots, or wounds. Shortleaf pine, having fewer lenticels than do deciduous species, absorbs less water by this means. While several days lapse following a soil moisture recharge after drought before roots begin growth, absorption through suberized roots begins promptly

(Addoms, 1946; Kramer, 1946), and is important during winter when root growth is reduced and roots are suberized to their tips.

### Light

The vigor of individuals is delicately balanced by the interacting influences of light and moisture. The successful establishment of shortleaf pine at forest margins is attributed to high light intensity for carbohydrate manufacture, but shading also reduces size and rate of growth of roots (Oosting and Kramer, 1946). Ferrell (1953) considered light the variable most influential to seedling growth, and observed some survival response to light. For shortleaf pine, the relation of light to both survival and growth is linear and direct, the latter to at least 70 percent of full sunlight.

Light penetrates a shortleaf pine canopy to a considerable degree when basal area decreases below 70 square feet per acre (Fig. 6). Maximum

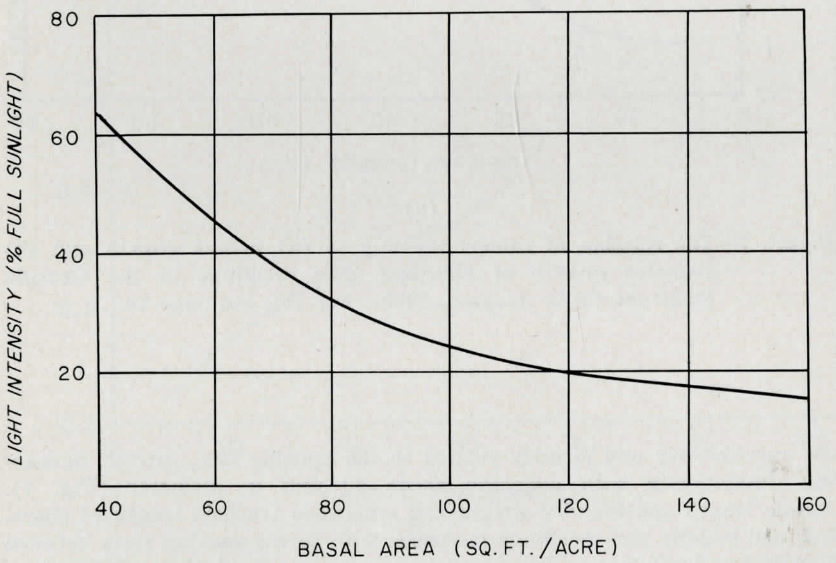
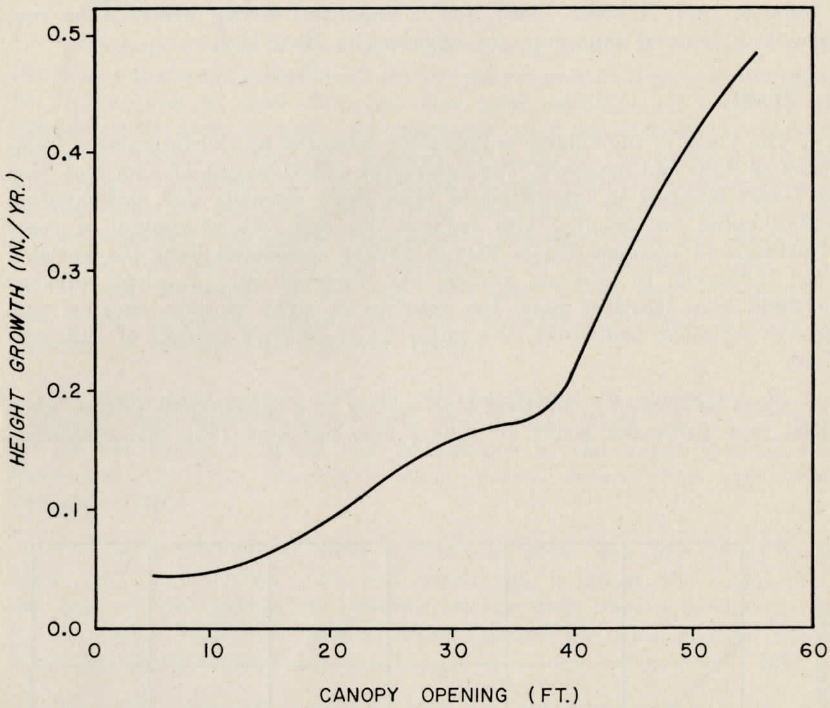



**Figure 6—The relation of basal area to the intensity of light penetrating a shortleaf pine forest (Jackson and Harper, 1955).**

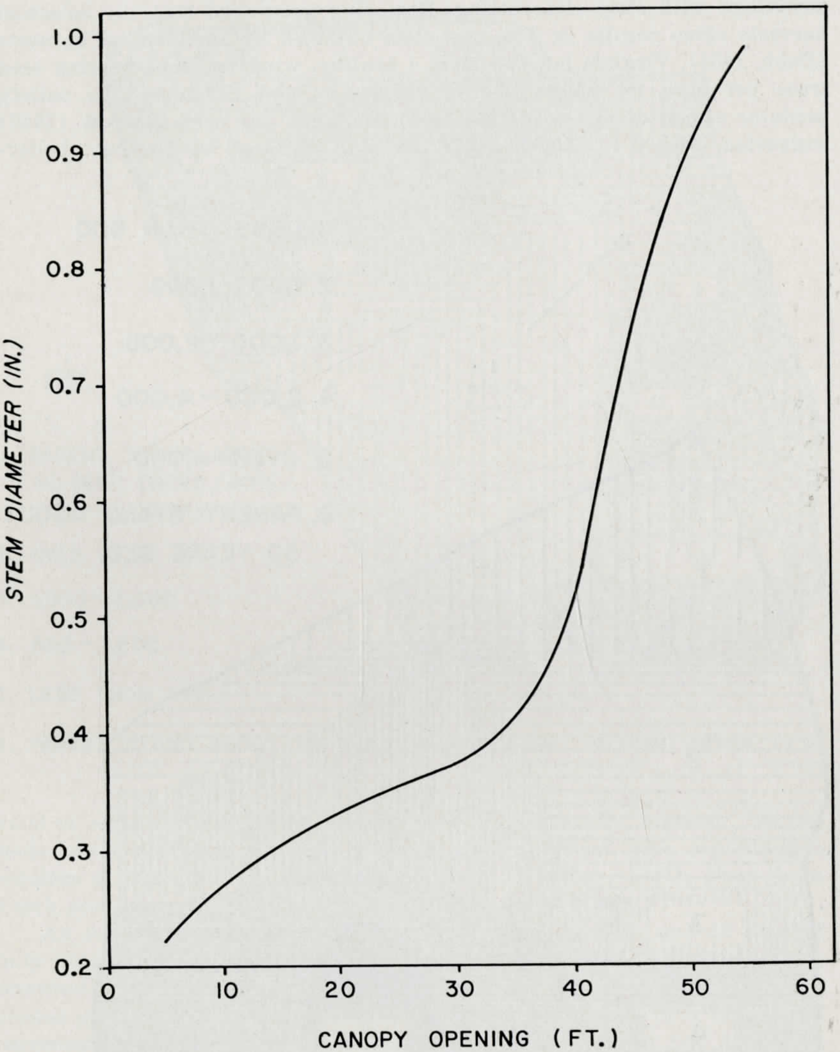
light intensity within a stand of 40 square feet basal area is about 65 percent of full sunlight. From 100 down to 40 square feet, light intensity increases about 40 percent in contrast to an increase of only 9 percent for a reduction of from 160 to 100 square feet per acre (Jackson and Harper, 1955). Along with basal area-light correlations, diameter and height growth




(a)

**Figure 7—The relation of canopy opening to (a) height growth and (b) diameter growth of shortleaf pine seedlings in the Georgia Piedmont (after Jackson, 1959). For (b), see page 19.**

are curvilinearly and directly related to the opening size, growth increasing dramatically with openings above 40 feet in diameter (Fig. 7). Needle length and ovendry weight and stemwood tracheid length of shortleaf and loblolly pine seedlings increased with forest opening sizes between 5 to 55 feet in diameter. Stemwood density decreased (Jackson, 1962). Survival of shortleaf pine is lower than for loblolly pine at any light intensity between 2 and 70 percent of full sunlight (Ferrell, 1953).




(b)

**Regeneration**

**Natural Regeneration**

Reproduction methods for shortleaf pine include (a) clearcut and plant, (b) seed-tree, leaving 10 to 15 stems per acre, (c) strip clearcutting, with open areas not more than 150 feet from uncut portions of the stand, (d) shelterwood, and (e) selection. Seeds coming only from the sides is a disadvantage with strip clearcutting. Removing good seed trees by selection harvests often results in less seed than obtained by shelterwood harvests (Hebb, 1955). Virginia law considers 4 healthy, windfirm, cone-bearing seed trees per acre, 14 inches dbh or larger, a bare minimum. To satisfy predator appetites and to obtain 1,000 seedlings per acre, Barrett (1940) suggested 200,000 to 300,000 seeds per acre, obtained by two-cut shelter-

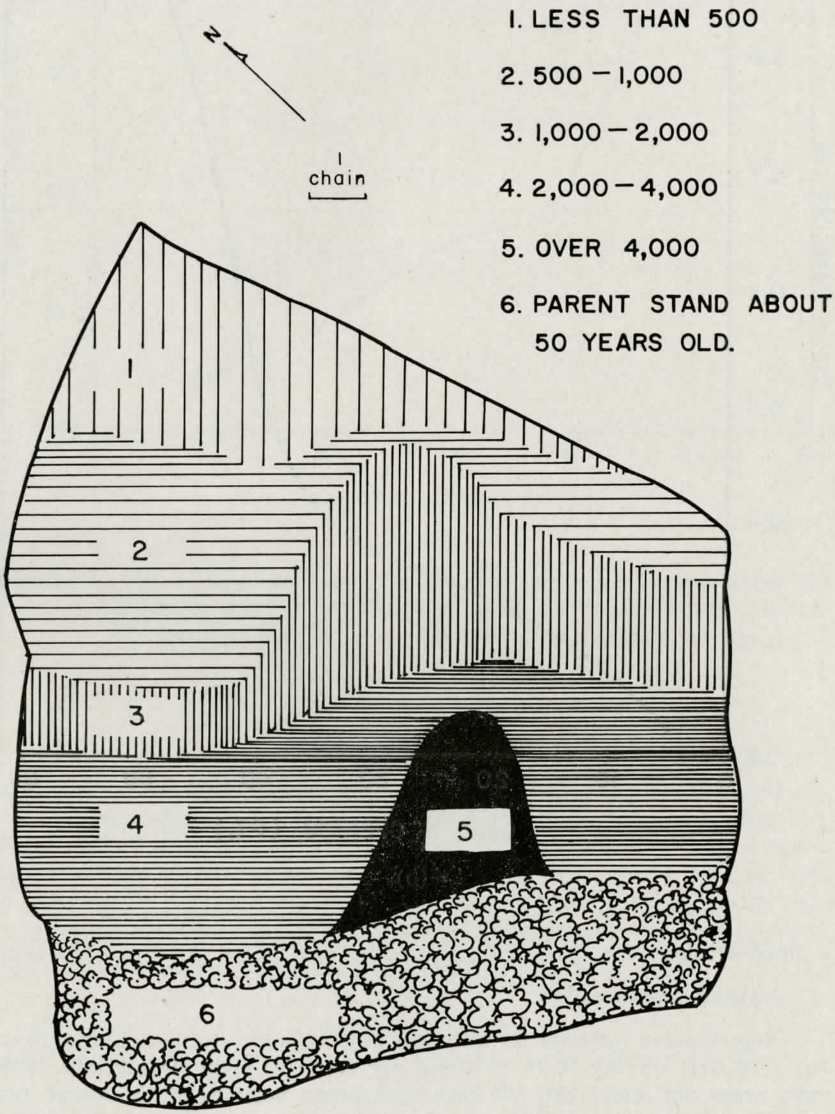
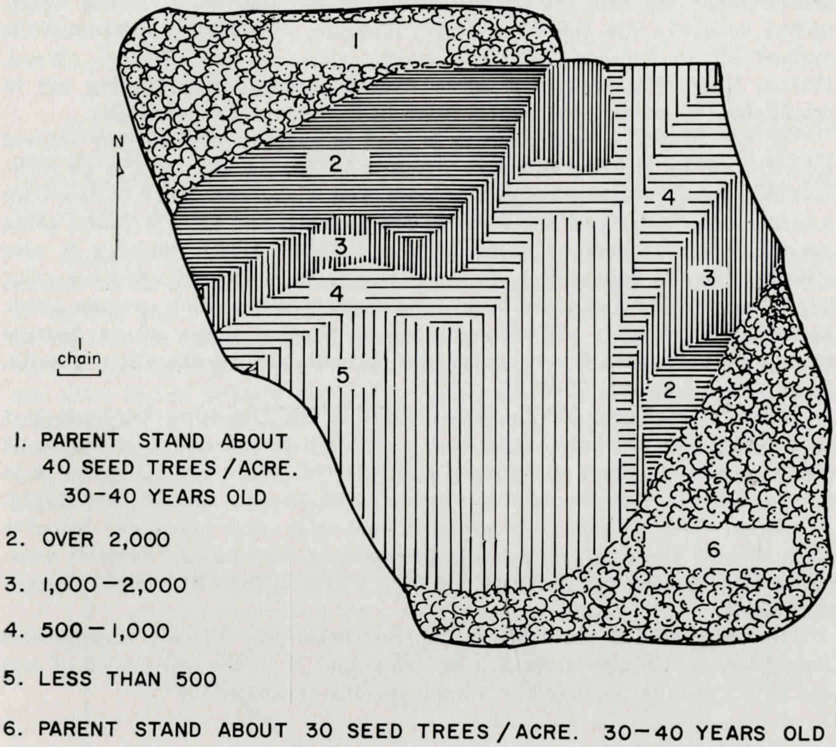



**Figure 8—Shortleaf pine-loblolly pine seed dispersal in the Piedmont (from McQuilkin, 1940).** **See also page 21.**




wood or strip clearcutting at 5-chain intervals. Generally, however, 100,000 seeds are considered adequate. Fair to good shortleaf pine reproduction requires at least 900 to 1800 cones per acre (Wakeley, 1947). Four 8- to 9-inch seed trees were found inadequate by Barrett (1940).

An adequate seed source is a stand 40 years or older and 50 percent fully stocked with trees—at least those at the edge of the stand—characterized by vigorous growth, well-developed crowns, and abundant cones. Parent stands should extend along at least one whole side of a field to be regenerated. A class I seed source produces 1000 seedlings per acre at a distance of 5 chains from the source and 500 seedlings at 7 chains. While stocking adjacent to a class II source is relatively good, the zone of higher seeding density is considerably narrower than for class I sources (McQuilkin, 1940) (Fig. 8). For shortleaf pines in the Arkansas-Louisiana area, the number of seed disseminated drops off drastically one chain from forest walls. The drop is sharpest in poor years. A Texas study showed seed dissemination beyond 3 chains was problematical (Stephenson, 1963).

For Piedmont conditions, shortleaf pine germination is greater on mattocked or disked than undisturbed soil (Ferrell, 1953; Haney, 1962). Mortality is serious in early summer after germination, especially where sites are not prepared, due to shade and inadequate soil moisture (Ferrell, 1953). Haney (1962) reported the ratio of the number of seed required to establish one seedling was 50:1 for the scarified seedbed, and 392:1 for the undisturbed seedbed. For the New Jersey Barrens, the turfy layer must be scalped off or thoroughly tilled; raking alone is not effective (Wood, 1939a). Bulldozing and, to a lesser extent, disking after logging aid in establishing shortleaf pine regeneration in Kentucky (Sander, 1963).

In the Ozarks, a rotary cutter is used to prepare seedbeds for natural reproduction by clearing brush in 7-foot-wide swaths. It is useful on rock-free sites, with moderate or gentle slopes, and where vegetation is less than 3 inches dbh. Litter and small stems are mulched and after 2 years, pines are above the sprouts of severed stems (Maple, 1960). Burning is also effective for site preparation on Ozark sandy soils. On silt and clay soils, it induces sprouting of shrubs and hardwood trees that may overtop pines. Prescribed burning is not recommended on erosive slopes where damage from soil movement likely outweighs benefits to regeneration (Smith, Bower, and Lawson, 1960).

Natural seedlings in unprepared sites in the Ouachitas survived best on south slopes and with grass-forb cover. Hardwood and pine-hardwood canopies caused severe mortality by the second year. Frost heaving was more serious in deep than shallow soils (Smith, Bower, and Blocker, 1961).

Even where seedbeds are prepared and seed crops adequate, droughts often destroy the crop. With a site prepared by burning and seedfall averaging 450,000 seed per acre, germination was less than 4 percent (Ferguson, 1958).

Severely eroded old-fields in the Southeast are difficult regeneration sites because summer temperatures reach 136° F in the top ¼ inch of soil and average daily maxima for 2-week periods approach 120° F.

### Sapling Release

Long-suppressed residual saplings respond in diameter increment to complete release by clearcutting of the overstory. Growth depends upon crown ratio at time of release; those with larger crowns continuing growth at the same rate. However, the increment in these residual saplings is so small and their presence so detrimental to volunteer seedlings within a radius of 10 feet that they should be removed in clearcutting (Brender, 1961).

### Other Problems

Air temperature 1 inch above the ground has been recorded at 118° F. Under these conditions, evaporation reduces soil moisture by as much as 8 percent in 36 hours, and 10 days without rain in summer leaves the surface soil so dry that shallow-rooted seedings are killed. Then when it rains, the impervious clay at the surface will not absorb an inch of water in 36 hours. In contrast, spots with original topsoil, like old graveyards, absorb 20 to 40 times as much water as fields long cultivated and depleted of organic matter (SEFES, 1951). Frost heaving in old-fields, alternate freezing and thawing occurring as often as 50 times each winter, may make mulching necessary for establishing trees. Mice, sometimes traveling a mile to get seed from cutover areas, have an average home range of about 1.25 acres (Stephenson, Goodrum, and Packard, 1963). Birds, picking seed coats off newly emerged cotyledons, and tree-killing ants also reduce germination and early survival.

**Prescribed Burning**

Shortleaf pine stands are prescribed burned for seedbed preparation and undesirable species control. Soils in which littleleaf malady is present or potential should not be burned, as incorporation of organic material into the mineral soil is necessary for improving structure.

Burning is used for seedbed preparation as older roughs have a detrimental effect on pine establishment and survival. Whether fires run with or against the wind makes little difference (Ferguson, 1958). One-fourth to one-half inch of pine litter remained after either type of fire in a stand with a sweetgum-post oak-red oak understory. In this area fuel was light and litter before burning was 0.2 inch deep under hardwoods and 1½ inches under pines. Growing season burns probably kill more brush than dormant-season fires. Germination, decreasing with time between burning and seedfall, is apparently hindered by litter accumulation and the return of competitive vegetation (Fig. 9).

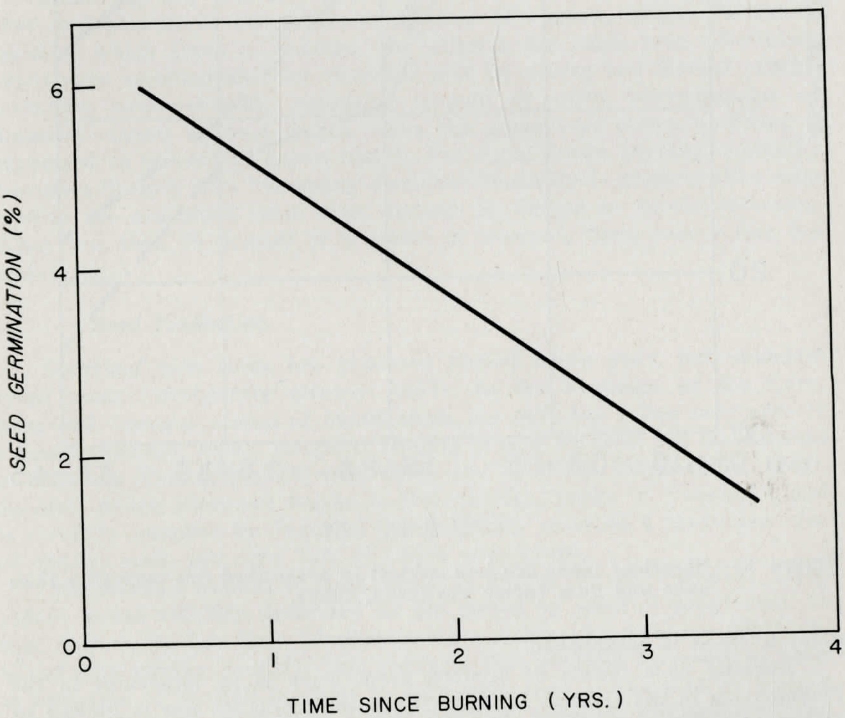



**Figure 9—Shortleaf pine seed germination by years since burning, in East Texas (from Ferguson, 1958).**

Mortality resulting from growing season headfires among East Texas shortleaf pines decreased appreciably as dbh increased. Beyond 4 inches dbh, mortality was negligible, while all seedlings less than ½ inch were killed. Shortleaf pines appear to be less subject to prescribed fire destruction than oak and gum and residuals will probably not be sacrificed in site preparation (Fig. 10). It may be desirable to remove them shortly

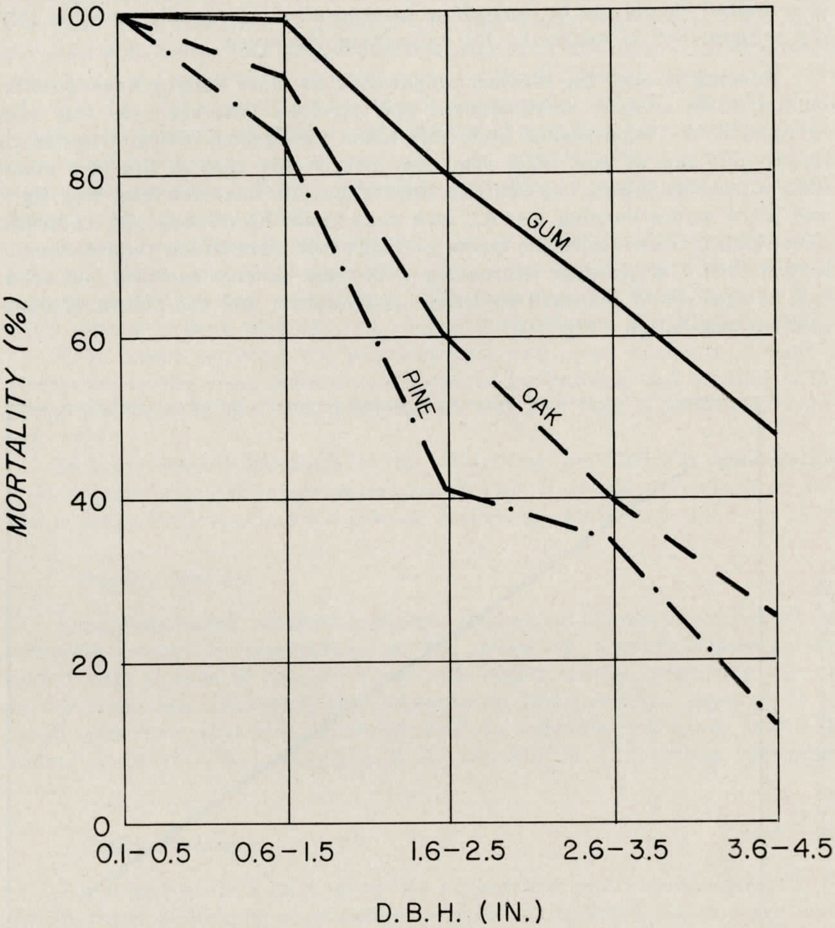



**Figure 10—Shortleaf pines are less subject to prescribed fire mortality than oaks and gum (after Ferguson, 1957).**

after a stand is established.

Burning as a means of seedbed preparation is as important in the Piedmont as in the Coastal Plain, but in rolling hills its use is limited to stands of brush and grass under overmature seed trees. Disking is more expensive, but less risky for seedbed preparation. It has not been determined under what conditions occasional burning for regeneration may be detrimental to the soil or the conditions under which fire might be used in this province. Williamson (1964) reported that the controlled burning of oak-pine stands on the Cumberland Plateau decreases the height of the hardwood understory, but greatly increases the number of stems, making it almost impossible to regenerate shortleaf pine.

In the New Jersey pine Barrens, prescribed burning for conversion of worthless hardwoods to shortleaf and pitch pines is practiced. Winter fires do not consume all debris, but do reduce its depth. Stand yields are not affected if crop trees are larger than 2 inches dbh, and basal wounds on pines are small and usually confined to stems less than 3 inches dbh. Fast-moving headfires are employed, as the shifting unsteady winds of the Jersey coast cause backfires to be too hot (Somes and Morehead, 1950). The typical basal crook at the tree base indicates those pines large enough to survive prescribed burning.

In the Ouachita Mountains, shortleaf pine seeds may lie in the duff for a year before germination. Untimely burning destroys these seeds. In unburned plots, seeds germinating a year late produced 40 percent stocking, while adjacent control-burned plots were only 7 percent stocked. Destruction of seeds by fire may be particularly serious following a bumper crop (Smith and Bower, 1961).

Following fire, shortleaf pine mortality depends upon depth of basal char and percent of circumference girdled (Ferguson, 1955). To aid in deciding which trees to salvage, the criteria for slash pine (McCulley, 1950) were recommended for shortleaf pine by Storey and Merkel (1960): mortality increases with increasing amount of crown browning for all diameter classes up to 6 inches, when the amount of crown browning is expressed as percent of crown length. For equal crown burning, mortality decreases linearly with increasing diameter. Mortality is greater when some needles are consumed than when damage is limited to needle browning. When less than 70 percent of a crown is browned, trees over 5 feet tall seldom die.

### Seed Production

Shortleaf pine seeds are produced almost every year, but abundant crops occur infrequently (Haney, 1957). In the Piedmont of the Carolinas and Georgia, a crop of 50,000 seeds per acre has fallen only once in 5 years (SEFES, 1959). Irregular seeding is also reported for the Barrens of southern New Jersey (Woods, 1939) and in Texas (Stephenson, 1963). Seedfall in the Piedmont begins in late October, peaks in November, and is virtually complete by January. Haney (1957) recorded a maximum crop of 228,000 seeds per acre, half of which were sound.

The seedfall pattern in East Texas is similar to the Piedmont. Hebb (1955) found viability decreased as the period of seedfall progressed, so that in January less than 30 percent were viable (Stephenson (1963) obtained very similar results). This suggests that seedbeds be prepared prior to initiation of seedfall in order to take advantage of the seed of highest viability. Clearcut strips had lowest seedfall, selection intermediate, and shelterwood the highest, ranging from ½ to 2 million seeds per acre. Releasing seed trees 19 to 22 months before the crop matured enhanced production. Phares and Rogers (1962) found the optimum stocking for maximum seed production in shortleaf pine stands about 40 years of age could be lower than 50 square feet basal area per acre. Their work also indicated that seed production was increased by removal of understory hardwoods, attributed mainly to the availability of more moisture for the pines. While partial cutting of overstory trees did not induce crops in years of widespread seed failure in Texas, it did increase the efficiency of individual trees in seed years (Stephenson, 1963).

Abundant seedfall generally follows or coincides with sharp drops in temperature preceding rain. These thermal lows, resulting from cold fronts, are accompanied by low humidity and high winds from the north and west which may be more important than rain and temperature in seed dispersal.

Although shortleaf pine is less seriously damaged by ice and sleet than other southern pines, perhaps relating to its more northern range, flowers are injured by freezing temperatures in the deep South. Female strobili in late stages of development were completely killed when the temperature dropped to 25° F in late March (Campbell, 1955). Those in the early bud scale stage, in contrast, were not injured. The technique of Trousdell (1950) for forecasting pine seed crops was found adequate by Read (1953) in spite of severe drought.

**Sprouting**

Shortleaf pine is the most prolific sprouter among the southern pines, especially after fire (Fig. 11). From 4 to 8 sprouts per tree frequently occur, some of which grow several feet the first year. The colonies break up after a few years, leaving one or more stems. These are generally of poor

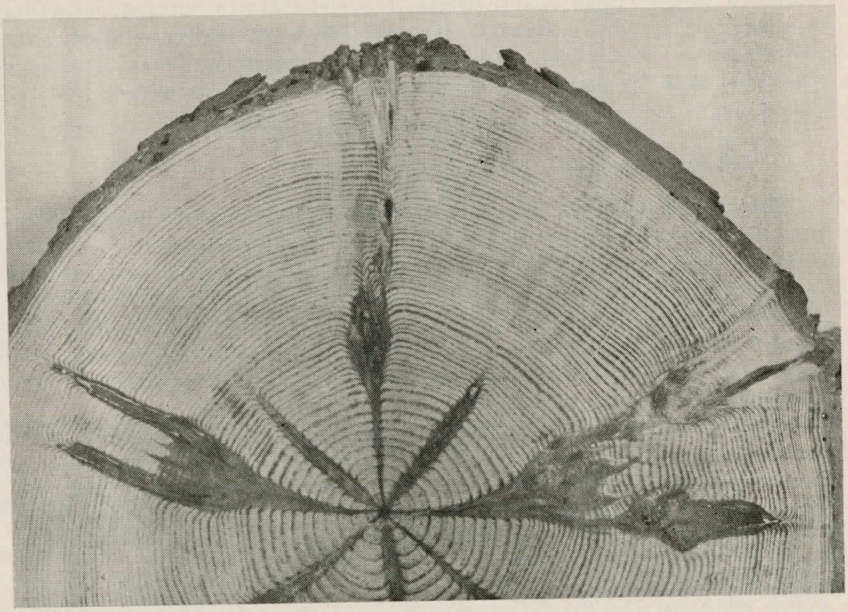


**Figure 11—Cross-section of bole showing bud traces of shortleaf pine (USFS photo).**

form and often give rise to forked trees. Second generation sprouts are common. Mattoon (1908) believed that sprouting was more vigorous after winter fires than after summer burns. Seedling sprouts are an important source of shortleaf pine reproduction, especially in the New Jersey Barrens, and are of better form, size, and vigor than sprouts from trees over 4 inches dbh (Moore, 1936). Young basal sprouts which develop from seedlings top-killed or weakened by fire tend to be tallest on the taller seedlings, probably because these seedlings have larger root systems to supply moisture and mineral nutrients for sprout growth (Phares and Crosby, 1962).

The Stones (1954) considered the collar from which sprouts arise as the juncture of the hypocotyl and primary root in seedlings or the zone of contact between root and stem in larger trees. Near the end of the first to third growing season, true or fascicle needles develop in the axil of upper and lower primary needles where the meristem capable of producing such needles is contained. All sprouts are traced to these axils and are not formed from adventitious buds.

For very young shortleaf pine seedlings, the stem falls prostrate as shoot growth begins, and then turns upward from a point just above the cotyledons, thus the crook. Primary needles with their axillary buds form a cluster just below the second bend of the crook, and further thickening engulfs the short horizontal portion. Rootlets from the uppermost root tissue arise close to the bud cluster which is often buried by soil movement or litter, a fact accounting for the oft-quoted theory that shoots arise from root tissue (Figs. 12 and 13).

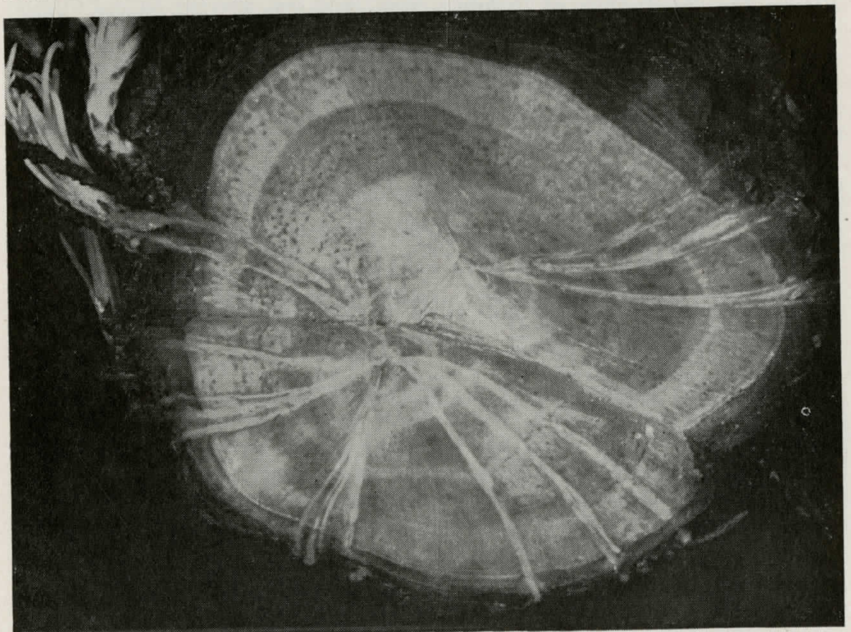


**Figure 12—Basal section of shortleaf pine, 3½ inches in diameter, showing branching of bud steles and their origin at the pith (from Stone and Stone, 1954).**

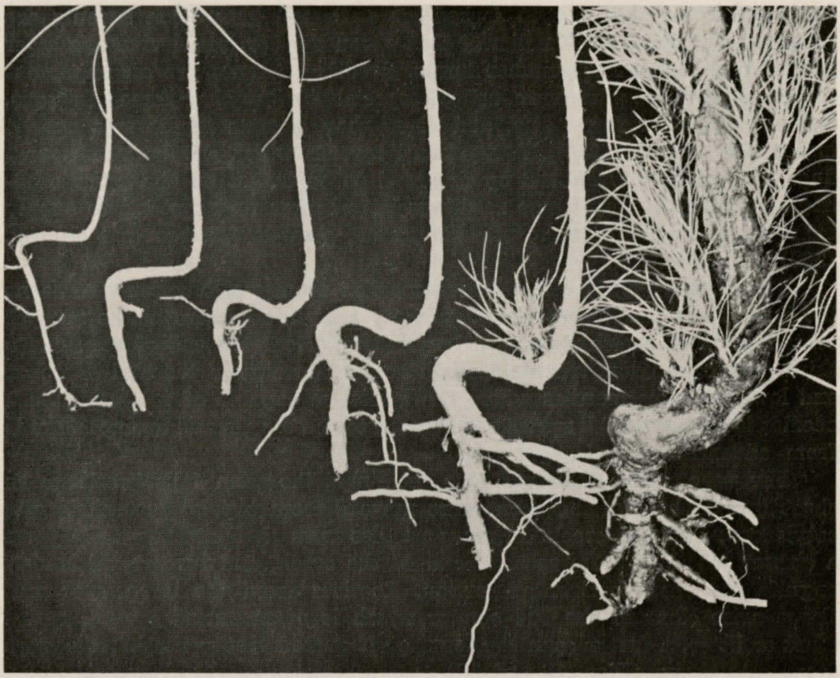


**Figure 13—Shortleaf pine seedlings with basal buds immediately above cotyledonary area and typical crook. On largest seedlings, buds have expanded following injury (from Stone and Stone, 1954).**

## Artificial Regeneration

### Planting

In the Tennessee Valley area of southwestern Virginia, shortleaf pine is recommended for poor sites which low-grade hardwoods now dominate. It is also recommended for all slopes and ridges. Poorly drained areas should be avoided, but severe erosion, even to the absence of the A horizon, is permissible for planting sites. Competing vegetation must be removed, except possibly sassafras under which planting has met with success (Minckler, 1941, 1941a, 1946a).

Shortleaf pine should not be planted on heavily vegetated steep shale sites in the Southern Appalachians. Under other geologic and vegetative conditions for the area, shortleaf pine growth is not affected by aspect, depth of top soil, seasonal rainfall, nor by the consistency of the B horizon (Minckler, 1943). Planting mixtures of shortleaf pine, yellow-poplar, black walnut, sweetgum and other hardwoods is questionable because of the superior growth but poor survival of shortleaf pine (Table 4).

TABLE 4. PLANTATION MORTALITY AND GROWTH AFTER FIVE YEARS AS AFFECTED BY PRECIPITATION THE FIRST GROWING SEASON AFTER PLANTING ON SEVERAL SITES (after Minckler, 1946).

| Species | Wet year planting | | Dry year planting | |
|---|---|---|---|---|
| | Mortality | Growth | Mortality | Growth |
| | Percent | Feet | Percent | Feet |
| Shortleaf pine | 28 | 5.7 | 26 | 5.3 |
| White pine | 27 | 3.9 | 36 | 3.7 |
| Yellow poplar | 32 | 3.0 | 38 | 2.8 |
| Black walnut | 75 | 1.4 | 93 | 1.1 |
| White ash | 28 | 1.9 | 43 | 1.6 |
| Sweetgum | 56 | 1.7 | 47 | 2.1 |

In northern Alabama, shortleaf pine does poorly on spoil banks where the top 2 to 4 feet of overburden is usually fine sandy loam or silt loam below which is a stratified silt, silty clay, brown shale, or fine sand to a depth of 10 feet (Freese, 1954). Coal spoils of a shale silty clay loam in southeastern Tennessee had satisfactory survival, but poor growth due to erosion which could have been prevented by waiting a few years for surfaces to stabilize before planting (Burton, 1961). In eroded broomsedge fields of the Piedmont, shortleaf pine plantings suffer more from close spacing than does loblolly pine but, regardless of spacing, the former species has 25 percent less basal area and half as much cubic foot volume as loblolly pine (Jackson, 1958). Early performance of loblolly pine was much better than that of shortleaf pine in test plantations in the Virginia Piedmont (Kormanik and Hoekstra, 1963). However, these workers noted that loblolly pine has during the past several years begun to suffer top damage in winter; this may forebode serious problems in planting the species out of its natural range. Also on adverse sites in northern Mississippi and western Tennessee, shortleaf pine growth is inferior to loblolly pine and, in addition, its sparse litter (for gully stabilization) and severe Nantucket pine tip moth injury limit its usefulness (Broadfoot, 1951; Williston, 1962, 1963).

Meginnis (1933) found it desirable to plow the severely-eroded bluff hill sites of loess material in order to loosen the soil before planting shortleaf pine. Check dams 16 to 18 inches high, using straw and stones behind dams to filter out sand and silt, are recommended along with seeding Bermuda grass or lespedeza at the lower face of the dam and on the soil behind it. The top of the dam is sloped so that drainage is at the center and not around the ends. On severely eroded heavy soils, bulldozing gullies and ridges with heavy equipment to form a large flat area, followed by seeding, appears to enhance site rehabilitation.

Shortleaf pine grows naturally near the West Florida Sandhills, but not within the coarse sandy sites. Excellent survival through the fourth year has been obtained by planting, and seedlings showed signs of outgrowing severe tip moth damage (Scheer, 1959).

Survival of shortleaf pine is probably not affected by deep planting stems up to three-fourths of their length. However, exposing even one-fourth of the root reduces survival significantly (Slocum and Maki, 1956). Root exposure of even a few minutes on a clear spring day seriously reduces survival (Cummings, 1942).

Summarily, planting with 1+0 stock generally should be at spacings of 6x6 to 8x8 feet, slightly deeper than seedlings were in the nursery bed, and without exposing roots to the atmosphere. The spacing at which seedlings are planted should vary with the owner's objective and expected survival. Bennett (1962) showed that at ages 20 to 35 the cubic yield of 200 trees per acre for unthinned stands of many conifers is better than half the yield from 1000, and the yield from 600 trees is 90 to 98 percent of the 1000-tree yield. Pointedly, the most suitable sites for planting this species are unknown, but it is so inferior to loblolly and slash pines that it is no longer produced in many nurseries. Seeds from inferior strains may have encouraged its disfavor, along with littleleaf disease.

**Seed Source**

An elaborate Southwide Pine Seed Source Study was launched by the Committee on Southern Forest Tree Improvement in 1951 to delimit practicable seed-collecting zones for the four major southern pines. Nineteen plantations included shortleaf pine, and while early results are published (Wakeley, 1961), definite recommendations will not be possible for some time. Meanwhile, the safest policy is to use seed from a local source for regeneration programs.

Shortleaf pine seedlings outplanted in southern Illinois on badly depleted old-fields varied in first year height growth, depending upon where in the South the seed originated. Coastal Plain Arkansas and Mississippi stock were superior to Ozark Mountain and Kentucky seed. Survival did not differ but foliage color variation was apparent, indicating differences, perhaps, in the nutritional status or photosynthetic capacity for out-of-range growth (Minckler, 1950). Gilmore (1963) substantiated earlier findings that the specific gravity of wood for this species decreases northward from southern Mississippi into southern Illinois, but he attributed this to either physiographic and/or climatic factors rather than geographic races. Severe freezes (to —22°F), occurring every 10 to 20 years, were more damaging for stock from Mississippi than for provenances further north. When local seed is not available, substitutes should be obtained east or west of the planting locality, rather than north or south of it (Wakeley, 1961).

**Direct Seeding**

Shortleaf pine has infrequently been direct-seeded. Excellent survival in the Cumberland Plateau of central Tennessee has been obtained. There, sites prepared by disking provide better seedbeds than those prescribed burned. Fourteen thousand seeds per acre coated with endrin-thiram repellents and latex sticker are suggested (Harrington, 1959; Mignery and Yeatman, 1960). Repellent-treated seed may be stored up to 20 days at ordinary room temperatures without adversely affecting germination and for longer periods in cold storage (Jones, 1963).

Direct seeding in the Ozarks where natural pine seed sources were unavailable due to burning and overcutting was successful when litter was removed, soil was cultivated, and the overstory reduced by 75 percent. This did not increase the catch the first year but did increase subsequent survival of seedlings—16 vs. 60 percent at the end of 5 years (Liming, 1945). One pound per acre of viable seed, equal to the production of 4 to 20 dominant pines per acre 12 to 28 inches dbh, was used.

Treatments that expose mineral soil improve stocking and survival of direct-seeded shortleaf pine in the Ouachita Mountains. Neither litter removal nor prescribed burning alone were highly effective site preparation techniques. While merely deadening hardwoods is not sufficient, (1) burning, (2) deadening hardwoods and burning, and (3) deadening hardwoods and furrowing have intermediate effectiveness (Bower and Smith, 1961). Furrowing is particularly desirable on silty soils which become compacted by rains that, thereby, hamper reproduction establishment.

Spot seeding in cultivated areas 18 inches in diameter with 12 viable seeds per spot in winter has given satisfactory results. Height of the tallest seedling—and one usually becomes dominant—was found directly related to the number of living seedlings in the spot after 1 year (Phares and Liming, 1961). Also, better results were obtained where spot seeding immediately followed removal of overstory hardwoods by girdling rather than by cutting or by girdling one year before seeding. It appeared that the shade from the recently-girdled trees protected the young seedlings from desiccation and insolation (Phares and Liming, 1961a).

**Tree Improvement**

Hybrids between shortleaf and loblolly pine occur naturally and have been produced artificially. This cross will probably become important commercially in the future on some sites (Mergen, Stairs and Snyder, 1965). For example, shortleaf x loblolly pine hybrids had no fusiform rust when growing in the middle of a slash pine plantation with about 70 percent infection (Henry and Bercaw, 1956). Shortleaf x slash pine hybrids are promising with respect to fusiform rust and Nantucket pine tip moth resistance, early vigor, and form (SFES, 1960).

Shortleaf pine tree improvement has been aimed principally at screening for strains resistant to the littleleaf malady. While no reproducable strains have yet shown superiority, techniques for vegetative propagation have been developed.

Air-layered 2½-year-old stock exhibited good root-forming ability, greater than for loblolly pine, and was aided by applications of 0.8 percent indolebutyric acid. Air-layering of branches is not successful if trees are more than a few years old. Over half of the needle fascicles air-layered on 2½-year-old trees produced roots and several had buds that broke dormancy and commenced shoot growth to become little trees (Zak, 1956) (Fig. 14).

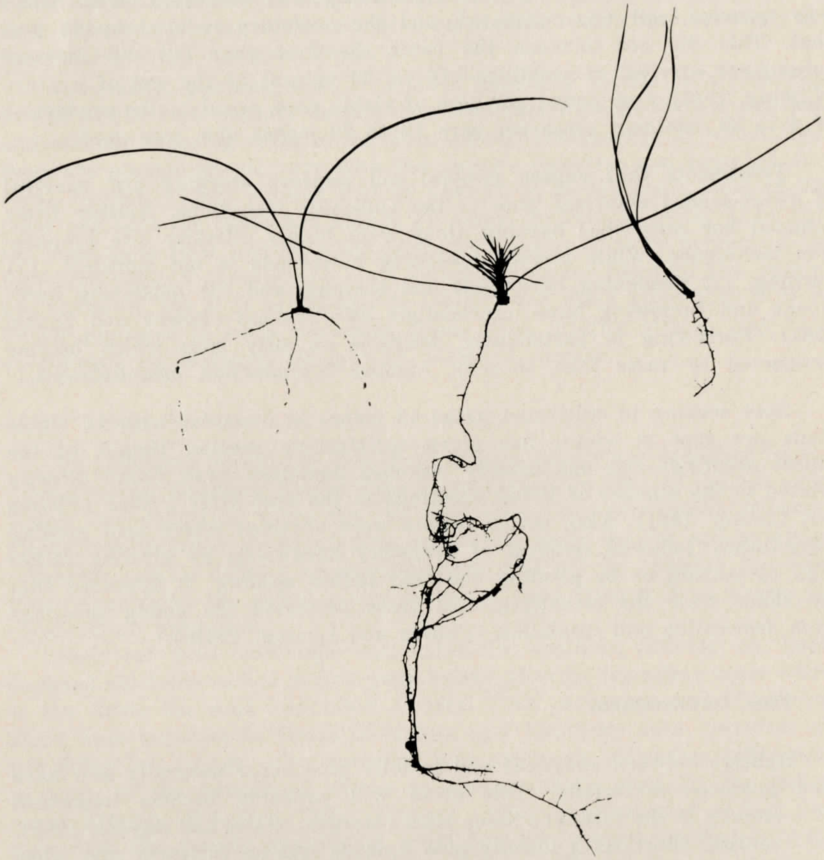


**Figure 14—Shortleaf pines developed from the rooting of needle fascicles (USFS photo).**

It is possible, but difficult, to root shortleaf pines in a 50-50 mixture of sand and peat moss. Cuttings were dipped in 0.8 percent indolebutyric acid, which is first mixed with talc, and given 24-hour light. Those that "took" had roots from ½ to 4 inches long (Zak and McAlpine, 1957).

A bark-patch technique for grafting has been developed, in which a diamond-shaped patch of living bark is cut from the stock, taking a thin layer of bark, phloem, and cambium. This is replaced in the spring, when bark slips easily, with a patch of identical size and shape from the scion, on which is a bud. Jackson and Zak (1949) also describe in detail the "approach" grafting method, in which stems of stock and scion are cut and fastened together. Shortleaf pine scions grafted onto shortleaf and loblolly pine stock have been used in a study of variation of tracheid length in clonal lines (Greene and Carmon, 1962).

The physiologic condition of shortleaf pine can be determined by the primary needle, its form varying with development. On young seedlings, it is needle-like; and then, beginning early in the second growing season, a brown scale appears. There are numerous instances of reversion to the needle-like juvenile type, especially on basal sprouts of cut seedlings. In discussing this, Bormann (1955) relates that cuttings with a slightly advanced stage of development have far less callus formation than younger material, but that cuttings which develop sprouts soon lose their ability to callus and, perhaps, to root.

### Intermediate Management

#### Thinning

A thinning guide, with basal area as the principal criterion, was developed by Morriss (1958) (Table 5). As site index and age increase,

TABLE 5. SHORTLEAF PINE THINNING GUIDE. BASAL AREAS INCLUDE ALL TREES 4 INCHES D.B.H. AND OVER (after Morriss, 1958).

| | Leave basal area (sq. ft.) for site index— | | | | | | |
|---|---|---|---|---|---|---|---|
| Age | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 20 | | | | 58 | 70 | 80 | 83 |
| 25 | | 55 | 69 | 82 | 88 | 91 | 92 |
| 30 | 55 | 72 | 85 | 92 | 93 | 95 | 96 |
| 35 | 68 | 83 | 92 | 94 | 96 | 97 | 98 |
| 40 | 77 | 89 | 93 | 95 | 97 | 98 | 99 |
| 45 | 82 | 90 | 93 | 95 | 97 | 98 | 99 |
| 50 | 84 | 91 | 93 | 96 | 97 | 99 | 99 |
| 60 | 86 | 91 | 94 | 96 | 97 | 99 | 99 |
| 80 | 87 | 92 | 94 | 96 | 97 | 99 | 99 |

a greater basal area may be maintained, approaching 100 square feet per acre on the best sites. The effect of stand age is much greater on the poorest sites—those 30 years of age carrying only a residual basal area of 55 square feet per acre while stands 80 years old carry almost 90 square feet. Morriss' guide is simple, yet not sacrificial to the art of thinning as quality rather than spacing receives major attention. To avoid mortality of shortleaf pines following thinning, trees more than 35 years old and with short or weak crowns should be harvested (Williston, 1950).

Abruptly changing growing space may result in changes in specific gravity of wood to be produced subsequently, depending upon how the earlywood : latewood ratio is affected. This ratio, directly related to soil moisture, is controlled by the silviculturist only when stands are so fully stocked that growing space and crown development may be regulated by conservative thinning practices after stands are past the juvenile stage (Paul, 1958).

Thinning may markedly increase available soil moisture in the middle and latter part of the growing season, as was found for 19-year-old plantations in north Mississippi. Not until the second year after thinning is the moisture increase associated with better diameter growth. However, even where water is usually abundantly available, growth rates are reduced during periods of rapid soil moisture depletion (McClurkin, 1961).

**Release**

Hardwood control to release understory pines may not be urgent, even when appearing so. For instance, the average annual height growth of shortleaf pine on land of SI 50 in East Texas is 15 inches for the first 10 years in contrast to 11 inches for hardwoods. Rapid hardwood growth is made in the first 3 years, and afterward it amounts to only about 10 inches per year. Becton (1936) developed a formula for determining if pine will hold its own on these low quality lands:

$$\frac{Y}{X}$$

where Y = average height of hardwoods **above** the pine, assuming both groups are the same age,

and X = average distance of at least 3 hardwoods from individual pines.

If the ratio is greater than 1.1, stagnation results, and pines are apt to be replaced by hardwoods.

After 5 years, annual release in northern Mississippi underplantings had not improved survival. Height growth, however, was doubled by release even though attack by the Nantucket pine tip moth was severe. Survival did not differ much between wet- and dry-year planting on these deep, sandy loam, dry, loess ridges of rapid internal drainage (Williston, 1958).

Shortleaf pines released promptly upon planting in the Cumberland Plateau grew twice as fast the first season and four times as fast the second season as did unreleased trees. Silvicides, by providing rapid kill, gave better height growth than girdling, but early release did not affect survival (Harrington, 1960).

In northern Alabama, shortleaf pine growth doubled by an improvement cutting which released conifers, but here the improvement was delayed a year, indicating, perhaps, that freed stems required that time to develop vigorous crowns before responding to release. Treatment consisted of removing undesirable hardwoods over 1½ inches dbh, which comprised 80 percent of the stand basal area of 50 square feet per acre (Freese, 1950).

Undesirable hardwoods in Ozark pine stands present a serious obstacle to obtaining high growth rates, because pines are on the warmer, drier southern and western exposures where fires are more frequent. Ground cover must be maintained to prevent erosion. Stand improvement may be in two treatments: cleaning or weeding of seedling- and sapling-size stems of the understory, which releases desirable trees of the same size; and cuttings to release the understory from overstory competition for light. Read (1951) suggests keeping desirable saplings at a spacing of 17x17 feet, and treating only trees interfering with crowns of desirable species so that well-formed stems of favorable individuals dominate the understory. Although the composition of the reproduction is not changed greatly by release, faster growth of the better species results in a great improvement in composition among the best 500 trees per acre (Brinkman and Liming, 1961).

Where pines have been planted in openings in stands of sprout reproduction, Liming and Siezert (1943) suggested leaving hardwood reproduction, as the pines will surpass many deciduous stems. Hardwoods overtopping pines should be removed within 2 years of underplanting. Understory trees may benefit by removal of the overstory, regardless of the method, season, or degree of release. Growth of pine-hardwood stands in the southern Appalachian Mountains is not affected by cutting of the understory (Lange, 1951).

**Pruning**

Shortleaf pine does not prune well naturally: dead lower branches persist for as long as 50 years. Pruning young stems favors development of more cylindrical basal sections. Cummings (1942) noted marked decrease in stem taper for trees pruned in the spring of the fourth year after planting. As diameter growth at heights of 1½ and 4½ feet was significantly reduced two seasons after severe pruning, treatment should never exceed one-half of the total height. Growth in the remaining crown, however, is not affected by pruning. Selection for pruning of 150 to 200 of the best trees when 3 to 5 inches dbh and 15 to 25 feet tall is suggested, removing branches to 8 or 9 feet. When trees are 35 to 40 feet, and 5 to 8 inches dbh, stems are again pruned to 17 feet. Low branches can be more readily severed with hatchet than with saw (Garin, 1955; Minckler, 1955).

**Nutrition**

Many nutritional studies of shortleaf pine were attempts to correct or prevent littleleaf disease. However, Roth and Copeland (1957) obtained diameter growth increases in healthy 30-year-old trees in South Carolina that received broadcast applications of the following nitrogenous fertilizers: sodium nitrate (16 percent N) at 1 ton per acre; sodium nitrate plus gypsum at 1 and ½ ton, respectively; gypsum alone at ½ ton; ammonium sulphate (20.5 percent N) at 1,600 pounds per acre; and an organic source (6 percent N) at a rate of 2½ tons per acre. Later work failed to show volume increases in shortleaf pines under 12 inches dbh when fertilized with a 3-9-6 formulation at 2,000-pound rates, but when an additional 1,000 pounds per acre of nitrogen were added to the complete fertilizer, diameter growth doubled (Roth and Evans, 1958). In Georgia, Jackson and Cloud (1958) found an appreciable increase in stem growth during the first year after a March surface application of 200 pounds per acre of ammonium nitrate (33.5 percent N) fertilizer.

A highly significant increase in diameter growth was obtained using 100 pounds per acre each of nitrogen and $P_2O_5$ in a silt loam loess soil in Illinois, but there was a 1-year delay in response to treatment (Boggess and Gilmore, 1959; Gilmore and Boggess, 1960). The fertilizers were broadcast in March prior to the beginning of diameter growth in a stand averaging 775 trees per acre.

A 22-year-old plantation of shortleaf pine with a basal area of 180 square feet per acre continued to respond to an application of 100 pounds per acre each of nitrogen and phosphate 2 years after treatment. Phosphorus with the nitrogen was only slightly better than nitrogen alone. While check plots grew 3.5 percent, diameter increment of nitrogen-treated stems was 4.6 percent. Had the stand not been overstocked, greater growth may have been attained (Boggess and Gilmore, 1960). Curlin (1963) found a significant increase in basal area growth in thinned 13- to 50-year-old shortleaf pine stands 2 to 4 years after fertilization with ammonium nitrate (33.5% N; 300 pounds of available N per acre). Phosphorus treatments had varied and often adverse effects.

Seed production in a 37-year-old shortleaf pine stand in Missouri, thinned to about 45 square feet of basal area per acre, was increased by application of commercial fertilizers. Trees fertilized with large amounts of phosphorus and potassium produced about twice as many sound seeds as the check trees. The application of large amounts of nitrogen resulted in a smaller increase in seed production (Brinkman, 1962).

Boggess (1959) reports that 17- to 20-year-old plantations in southern Illinois thinned to 80 square feet basal area show, after 2 to 3 years, 1.3 percent nitrogen in foliage at the end of the growing season compared to 1.2 percent for unthinned stands. The difference, greatest on the better sites, may be due to the "more rapid breakdown of litter caused by increased sunlight reaching the forest floor and to the additional nitrogen made available per tree when more than one-third of the basal area was removed. Then, too, the decay of plant residues after cutting adds humus to the soil." Survival of planted seedlings was not appreciably improved in these deep silt loam loess podzolic soils treated with various fertilizers and manures over a 35-year-period prior to abandonment from agriculture (Boggess and Gilmore, 1960).

Twenty-seven different mixes of complete fertilizers applied in mattock holes at time of planting in Ohio failed to induce significant increases in height growth (Cummings, 1941), possibly because of root "burning."

In a greenhouse study, Hobbs (1944) obtained highly significant reduction in growth of shortleaf pine seedlings in sand cultures lacking nitrogen, phosphorus, or potassium. Deficiency symptoms, based on 3 years of observations, were manifested by pale-green, short needles, with stunted growth for low nitrogen levels; necrosis progressing upward from lower needles and stunted growth for phosphorus deficiencies; blue-green needles with copper-colored terminal necrosis for insufficient potassium; and tip chlorosis of needles and reduced growth for deficient magnesium. Wilson (1953) found that 0.1 part per million of zinc is necessary for normal shortleaf pine growth: seedlings with less zinc had abnormally small needles.

Jemison (1943) in North Carolina found a significant decrease in growth of trees 10 to 13 inches in diameter when litter down to mineral soil had been removed annually for a 12-year period. Perhaps essential elements were removed from the site more rapidly than replenished by soil genesis.

The high calcium content in the soil of abandoned fields, accompanied by high pH, could be responsible for preventing natural reproduction and successful plantation establishment of shortleaf pine. Chapman (1941) found germinating seed and young seedlings tolerant of soluble calcium of 500 parts per million or less. In terms of pH, tolerance is 6.5 or less.

## Injurious Agents

### Diseases

Basal wounds probably cause most cull in shortleaf pine. Open wounds at butts have much more cull than those grown over, but top cull is usually about the same for open and closed wounds (Gustafson, 1944). Of the rot fungi, **Fomes pini** is the most common pathogen in older trees (Table 6).

TABLE 6. PERCENTAGE OF TREES WITH RECOGNIZED INFECTIONS (after Hepting and Chapman, 1938).

| Area and fungus | Trees infected |
|---|---|
| | Percent |
| Arkansas | |
| *Fomes pini* | 19.0 |
| *Polyporus schweinitzii* | 1.3 |
| Undetermined | 6.4 |
| TOTAL | 25.5[1] |
| Texas | |
| *Fomes pini* | 30.9 |
| *Polyporus schweinitzii* | 11.2 |
| Undetermined | 1.4 |
| TOTAL | 37.3[1] |

[1]These figures are not the sums of their respective column because many trees contained more than one fungus.

Cankers formed by the rust fungus **Cronartium cerebrum** are occasionally serious in shortleaf pine. The pitch canker fungus **Fusarium lateritium** attacks some trees, but cutting diseased trees and pruning diseased limbs may offer some local control (Hepting and Roth, 1946). Although **Fomes annosus** has been reported on shortleaf pine stumps in the Piedmont, damage in natural stands is rare (Dwyer, 1951). Several needle cast fungi attack this species, but they are not economically important.

### Littleleaf Malady

#### Site and Cause

Littleleaf, first reported in 1934 in Alabama, is now the most serious disease of shortleaf pine in the Piedmont and especially in South Carolina. It is found as far north as Virginia, west to Mississippi, and south to the Gulf Coast. The problem is recent, occurring only with the reforestation of severely eroded lands abandoned from agricultural cropping. Originally, much of the deep friable, rich soils, although underlain with heavy and poorly drained subsoils, bore hardwood climax forests. The A horizon, in which roots are most abundant, was deep and well-drained. With cultivation, however, the surface soil eroded, leaving a thin mantle which forced roots to grow in the impervious, poorly aerated subsoils. Under such conditions, littleleaf is found (Zak, 1957).

Littleleaf results from the gradual killing of fine absorbing roots by the parasitic soil fungus **Phytophthora cinnamomi** and probably, to a lesser extent, from other causes. Campbell **et al.** (1953) observed that death of new root tips—those most susceptible to periodic killing—interfered with absorption of nutrients, especially nitrogen. "Littleleaf does not develop merely from the presence of **Phytophthora cinnamomi** in the soil. This fungus is widely distributed and probably is causing the loss of some root ends and fine roots in southeastern pine stands generally. In well-drained soils the periods in which sufficient moisture is present for swarm spore production, and subsequent root infection, are limited only to the actual periods of extended rainfall. In the ensuing intervals, because these well-drained soils provide optimum conditions for root growth, new roots form and effectively replace those lost by infection. In poorly drained soils the periods of high moisture are extended and root recovery is appreciably retarded by less favorable physical properties of these soils. Furthermore, roots in these soils suffer from poor aeration and the possible accumulation of toxic metabolic substances during wet periods. Trees in locations lacking appreciable topsoil are forced to develop roots in soils that offer great variation in moisture conditions as well as increased resistance to root penetration. Such soils become excessively wet during rainy periods, and, because of a relatively low available water-holding capacity, become excessively dry when rainfall is low. These conditions adversely affect root development and at the same time accentuate the effects of root mortality caused by parasitic fungi" (Campbell and Copeland, 1954).

Close relationships exist between soil internal drainage and disease incidence, as it is most abundant on severely eroded areas where heavy, poorly drained subsoils underlie a shallow surface layer. Poorly drained soils are worse, perhaps because swarm spores which cause infection require abundant water. Zak (1961) noted greatest damage when **P. cinnamomi** is introduced into heavy soil with excess water. Poor internal drainage, too, is associated with adverse aeration, biotic, chemical, and physical conditions.

In addition to poor drainage, shallow soils that are severely eroded; highly variable as to porosity, permeability, compactness, or plasticity; and low in fertility may well be regarded as likely littleleaf sites. The malady may even occur where sandy surface soil is underlain by less permeable layers, causing an accumulation of water or a perched water table. On soils with an abundance of the water mold fungus, but possessing excellent internal drainage, stands suffer little infection.

Copeland and McAlpine (1955) found a mean site index of 60 for littleleaf diseased sites. Although there was little variation about this mean, the lowest site index on northeastern slopes was highly significantly different from the highest on northwestern aspects. Site capacity, as it is related to erosion, bears a relationship to littleleaf malady, for where erosion was slight and site index over 60, only 4 percent of the trees were infected. But where erosion was severe or the land rough and gullied, and site index just above 50, over half of the trees showed symptoms of the malady.

Seldom are trees under 20 years of age severely attacked. The belief that physiological aging of trees is accompanied by a decline in vigor and hence in regenerative capacity of root systems allows a plausible explanation for the occurrence of littleleaf in trees only over 20 years old. Trees are less likely to recuperate as they grow older (Zak, 1961). Most damage to roots occurs in early spring and late autumn when soil temperature and moisture are favorable coincidentally with periods of maximum development of new root tips. Anaerobic conditions in heavy soil, resulting from excessive soil water, then prevail. The malady may be temporarily averted if new roots can be formed after attack (Zak, 1961; Zak and Campbell, 1958). But this is difficult, as the root bark of diseased trees often has less than half as much food as that of healthy trees (Jackson and Hepting, 1964) and at times, reserve food is almost absent. Roots, normally storing more food than stems on a weight basis, and for which the amount fluctuates more seasonally, suffer most from inadequate nutrition. The loss of this vital tissue means that recovery from littleleaf by site treatment, including fertilization, requires several years as these reduced root phloem storage tissues must first be made healthy enough to accommodate normal amounts of starch (Hepting, 1945).

Littleleaf incidence is high where broomsedge or other grasses are abundant and soil nitrogen is low. Where old-fields are covered predominantly by herbaceous and shrubby plants, the amount of littleleaf is lower and, as may be expected, site index and soil nitrogen are higher (Copeland and McAlpine, 1955).

According to some studies, the incidence of littleleaf disease varies with soil associations but not by slope or erosion classes—perhaps they were too broad. Neither was its occurrence influenced by position on slope, aspect, soil texture, or soil pH (Copeland, 1949; Copeland and McAlpine, 1955).

Shortleaf feeding roots are most abundant in the upper few inches of soil; while loblolly pine, in contrast, has fewer feeding roots than shortleaf pine, and these are larger in size, more deeply distributed, and show greater ability to penetrate heavy soils. The fact that the disease organism attacks feeders which are concentrated in a smaller soil volume for shortleaf than loblolly pines may account for the greater abundance of littleleaf disease in the former. Loblolly pine is also more tolerant of poor soil aeration and has a higher inherent vigor than shortleaf pine (Zak, 1961; Copeland, 1952).

### Symptoms

Early symptoms are slight yellowing of foliage with a tendency for the current year's needles to be shorter than normal. Small, sparse tufts of chlorotic needles later appear at the ends of twigs. Although needles turn yellow-green in fall and winter, they have a more normal color in spring and early summer.

Severe littleleaf areas may give the impression that a catastrophe has occurred. However, branch ends on trees with littleleaf have an abruptly ascending habit because the stunted, sparse foliage is too lightweight to counteract the influence of negative geotropism. Insect-killed trees, in contrast, have horizontal branches. Dominant and codominant stems are killed as frequently as suppressed trees.

A marked reduction in carbohydrate synthesis accompanies the external symptoms to the extent that reserve food production of the foliage is less than 10 percent of normal for trees with advanced littleleaf (Hepting, 1945). A striking effect, and a symptom, of root starvation is the accentuated formation of rough bark owing to the cork cambium cutting deeply into the food storage region of the phloem. Thus, less storage tissue remains in root bark and less food, therefore, is needed to satisfy the storage capacity.

With Monterey pine in Australia, a great capacity has been shown for rootlet regeneration following severe damage from drought, flooding, or **P. cinnamomi** infection. Flooding can kill roots, but at only a fraction of the rate of destruction by the organism and flooding together. Ordinarily rootlets lost are restored in time to support spring growth. However, symptom expression depends on destruction of the balance between transpiration demand and absorptive capacity of the root system; if rootlet mortality is heavy in autumn and winter and continues into spring because of excessive soil moisture, trees suffer from physiological drought at a time when water demand is rising rapidly. Trees with a large transpiring surface may wilt quickly; where attack is less severe, trees defoliate and new shoot and needle growth are reduced, but with the now reduced transpiring surface they can tolerate severe rootlet damage and behave as though resistant (Newhook, 1959). Susceptibility of Monterey pine increased and the recovery rate decreased with increasingly poor drainage (Sutherland, 1959).

A survey by Roth (1960) indicates a wide variation in rate of deterioration among stands, depending, principally, upon soil characteristics (Fig. 15). Only 30 percent of healthy dominants and codominants in severely infected littleleaf areas remained vigorous for 15 years. The average life of an infected tree is about 6 years after symptoms appear.

Diameter growth probably remains about normal until symptoms are obvious—due to stored carbohydrates that supply sustenance—and then decreases with foliar decline until annual increment is only a few hundredths of an inch, just prior to death. Jackson (1951), using dendrometers, measured growth at half that of healthy stems. Cone crops of diseased trees are heavier than normal, cones and seed are small, and viability is correspondingly low.

**Hazard Estimation**

The littleleaf hazard can be estimated for trees 30 to 65 years old by site index. As trees age and show no symptoms of the malady, the

**Figure 15—Soil profile of a Piedmont littleleaf site. The surface 6 inches is infertile sand—low in nutrients and water-holding capacity. Below is mottled clay of the B horizon, indicative of poor drainage, poor aeration, and retarded root growth (USFS photo).**

expected littleleaf incidence is greatly reduced. Copeland (1954) developed the regression

$$Y = 62.53 - 0.816X$$

when Y = percent of littleleaf expected,
and X = site index.

Thus stands with

SI 40 have a 30 percent incidence expectation.
SI 50 have a 22 percent incidence expectation.
SI 60 have a 14 percent incidence expectation.
SI 70 have a 5 percent incidence expectation.
SI 80 have a 0 percent incidence expectation.

Another rating scale for estimating littleleaf hazard was developed by Campbell *et al.* (1953) and Copeland (1954) (Table 7).

TABLE 7. A SOIL RATING SCALE FOR ESTIMATING THE LITTLELEAF HAZARD OF A SITE, IN WHICH THE HIGHER THE INDEX THE LOWER THE LITTLELEAF HAZARD. SEVERE LITTLELEAF AREAS WILL TOTAL LESS THAN 50 POINTS, AND LIGHT TO MODERATE LITTLELEAF AREAS FROM 50 TO 75 POINTS (from Campbell *et al.*, 1953).

| Soil characteristics and class | Points |
|---|---|
| Erosion | |
| Slight | 40 |
| Moderate | 30 |
| Severe | 20 |
| Rough Gullied | 10 |
| Subsoil consistence | |
| Very friable | 32 |
| Friable | 24 |
| Firm (slightly plastic when wet) | 16 |
| Very firm (plastic when wet) | 8 |
| Extremely firm (very plastic when wet) | 0 |
| Depth to zone of greatly reduced permeability | |
| 24"—36" | 15 |
| 18"—23" | 12 |
| 12"—17" | 9 |
| 6"—11" | 6 |
| 0"— 6" | 3 |
| Subsoil Mottling | |
| None | 13 |
| Slight | 9 |
| Moderate | 5 |
| Strong | 1 |

Terms requiring explanation are:

**slight erosion:** A1 not altered appreciably; not more than 25 percent original A removed.

**moderate erosion:** eroded to the extent that ordinary tillage implements reach through the remaining A1; 25 to 75 percent of the original A is lost; shallow gullies may be present.

**severe erosion:** all A horizon is gone, part of B lost to erosion; shallow gullies common.

**rough, gullied land:** pattern of deep gullies; soil profiles destroyed except in small areas between gullies.

**very friable:** soil material crushes under very gentle pressure, but coheres when pressed together.

**friable:** soil material crushes easily under gentle to moderate pressure between thumb and forefinger, and coheres when pressed together.

**firm:** soil material crushes under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable.

**very firm:** soil material barely crushes between thumb and forefinger.

**extremely firm:** soil material cannot be crushed between thumb and forefinger, must be broken bit by bit.

### Nutrition

Diseased shortleaf pines are deficient in nitrogen and calcium in foliage and have "somewhat" lower contents of manganese, aluminum, and copper than do healthy trees. Nitrogen fertilizers exceeding 200 pounds per acre reduce the incidence among healthy trees adjacent to infected stems, probably through root-growth stimulation which enables absorption of nitrogen and calcium. Improvement is also induced among some diseased trees, as measured by increased needle length, shoot growth, and needle color (Copeland, 1952; Roth, Toole, and Hepting, 1948; Roth and Copeland, 1957; Roth and Evans, 1958) (Fig. 16).

Where trees failed to recover with nitrogen supplements, foliar


**Figure 16—Littleleaf-diseased trees. At left, before being fertilized. At right, six years after application of nitrogenous fertilizers (Roth and Copeland, 1957; USFS photo).**

nitrogen remained low and the trees were probably beyond being able to assimilate the element even when in excess. However, normal amounts of most other elements are absorbable by roots of diseased stems. It should be clear that littleleaf malady is not simply a nitrogen deficiency. Even where this element is adequate for plant growth, it is probably not accumulated in plant tissues against a gradient, which results in a nutritional imbalance.

Three years after fertilizing 30-year-old trees with 320 pounds per acre of nitrogen, this element in foliage was as high as it was 1 year after treatment. Treatment raised nitrogen in needles from about 1 to almost 2 percent. Fertilization again at the end of the third year gave no further increase in foliar nitrogen, probably due to the availability of some nitrogen in the soil 3 years after treatment. While growth increases with nitrogen uptake, it does not with calcium amendments, although calcium is readily absorbed in both healthy and diseased trees.

Leaf mold—40 tons per acre—does not increase nitrogen in foliage nor is improvement in growth noted. Over a rotation, however, this treatment would be highly beneficial to sites with a history of littleleaf disease.

Interestingly, it is indicated that seedlings inoculated with a mycorrhizal fungus along with the littleleaf pathogen grow considerably better than those to which **P. cinnamomi** alone is introduced (SEFES, 1960).

### Treatment

Recommendations for littleleaf areas include:

(1) provide close surveillance of shortleaf pine stands, as trees 20 years and over deteriorate rapidly once the symptoms are obvious,

(2) grow pines in short pulpwood rotations, and

(3) in stands 30 to 50 years old in which the disease is present:

(a) cut lightly on a 10-year cycle if an occasional tree has symptoms,

(b) cut all diseased and suspected trees on a 7-year cycle if 10 to 25 percent show symptoms, or

(c) cut all shortleaf pines if more than 25 percent show symptoms. Harvesting only infected trees rather than clearcutting may be desirable, as trees apparently resistant to littleleaf occur together with infected stems. The forester may want to depend on these individuals for seed, assuming that such trees represent strains resistant to the malady.

(4) encourage hardwoods and favor loblolly pine—it is about one-third as susceptible to disease—or Virginia, pitch, and longleaf pines. Lespedeza is also effective in building up the soil and, when fertilized heavily, does well on littleleaf sites (Henting and Jemison, 1950). Kudzu should not be used because of its difficult control when sites are to be regenerated.

(5) cut diseased trees promptly as bark beetle infestations build up in standing dead trees and spread to healthy stems.

(6) fertilize with 250 pounds per acre of nitrogen or 1 ton per acre of 5-10-5 complete fertilizer plus 150 pounds per acre of nitrogen. The fertilizer should not be worked into the soil as feeder roots are thereby damaged.

(7) go by soil rating in Table 7 to determine risk for healthy stands up to 50 years old.
(8) manage healthy stands over 50 years normally, as these probably will not become infected.
(9) plant shortleaf pine only if scale rating from Table 7 is more than 75, except that the species may be used for short rotations between ratings of 50 and 75 (Campbell *et al.*, 1953).

Proper identification of soil series aids in estimating the potential littleleaf hazard, but past land use exerts a strong modifying influence on erosion and internal drainage so that series alone provides only a rough indication.

Hardwoods on a littleleaf site should be dealt with lightly, if at all. Soil build-up over the years through broadleaf litter decay and organic matter incorporation may eventually improve the site sufficiently to lessen the malady. Under severe conditions it may be necessary to leave even diseased trees, lest logging should scarify the site and further erosion take place. Litter, including twigs, falls at over 4,000 pounds per acre per year for pine and hardwood stands. Leaf-fall alone is usually between 3,000 and 4,000 pounds per acre, returning to the soil about 12 pounds of nitrogen and 18 pounds of calcium for pines and 25 and 90 pounds of nitrogen and calcium for hardwoods. Redbud, dogwood, and hickory have about 3 percent calcium in foliage in contrast to ½ percent for southern pines. Nitrogen is about 0.3 percent for pine, over 0.6 for hickory and dogwood, and over 1 percent for redbud. For dogwood, hickory, and yellow-poplar, but not for some other hardwoods, magnesium is about three times higher than for pines—0.7 versus 0.2 percent (Metz, 1952). Hence, it is desirable to favor hardwoods for rehabilitating littleleaf sites.

### Insects

A pine sawfly is a serious pest to shortleaf pine in the Piedmont of Virginia and North Carolina and has defoliated considerable acreage as far south as Georgia. First year plantings of shortleaf pines in north-central Louisiana have been seriously attacked by two reproduction weevils, **Hylobius pales** and **Pachylobius picivorus.**

Unless otherwise cited, information contained in the remainder of this section is from Bennett, Chellman, and Holt (1958), Ebel, Merkel, and Kowal (1959), Jackson, Thompson, and Lund (n.d.), Nagel (1959), Harrison (1957), and Thatcher (1960). An excellent review of present knowledge concerning the southern pine beetle is available (Dixon and Osgood, 1961).

#### Southern Pine Beetles

Shortleaf pine is very susceptible to attack by southern pine beetles of the genus **Dendroctonus. Dendroctonus,** the generic name meaning "killer of trees," was first described in 1838. Its known distribution in 1960 was mapped by Kowal (1960). This beetle attacks healthy pines of all ages and especially those weakened by drought, lightning, fire, and wind. Epidemics often follow long periods of hot, dry weather, but otherwise, underlying causes of the outbreaks are unknown. Craighead (1925) suggested the possibility of increased sap density of this species during drought as a factor. During epidemics, new attacks of southern pine beetle often occur in large, irregular spaced groups with a definite directional pattern. Initially infected trees serve as "springboards" for infestation of surrounding healthy trees.

Death usually occurs relatively shortly after infestation. Trees attacked early in the season are dead by midsummer, and those attacked in the autumn are dead and abandoned by the insects the following summer. During periods between outbreaks, some beetle activity may occur in the mountains and the Piedmont province, but in the Coastal Plain the insect virtually disappears.

Attacks begin in the spring, about the time dogwood is in full bloom. Four to six generations are produced in a year on 30- to 40-day cycles, with considerable overlapping. Peak activity is in late summer and early fall, activity ceasing by November except during prolonged winter warm spells. Overwintering takes place in all stages.

The foliage usually begins to fade 10 days to 2 weeks after attack; small (¼- to ½-inch in diameter) yellowish-white pitch tubes like wads of gum form about entrance holes well up the bole, and reddish brown boring dust accumulates in bark crevices, cobwebs on the trunks, and at tree bases. The pitch tubes may be absent in unusually dry weather. Mid-trunks of trees are first attacked; the beetles then moving upward and downward. Large trees are generally attacked earliest. If trees have not yet died, beetle presence is evidenced by the stripping of outer bark by birds seeking larvae and adults. Sawlog-size trees then acquire a distinguishing buckskin appearance.

Winding, S-shaped (for **southern** pine beetles) galleries on inner bark and wood surfaces girdle trees with criss-cross tunnels. Eggs are laid in nuptial chambers off of the "S" tunnels in the phloem. In these galleries, adults, eggs, or whitish larvae (with glossy reddish-brown heads) are found if the attack is recent. Most of the brood is in the bark in older attacks. Young adults, ⅛-inch long—the size of a grain of rice, are soft and white, but soon harden and darken to dull brown. The forepart of the head is notched and the hind end of the body rounded. Adults, escaping through pin-size holes chewed in the bark, are carried great distances by wind. There is one exit hole per adult.

Most trees attacked are between 20 and 50 years old; few trees less than 6 inches dbh are infested. Stems less than 2 inches dbh or under 15 years of age are rarely infested. Over long periods, losses are small, according to Hoffman and Anderson (1945). The worst problem, perhaps, is the entrance of **Ceratostomella ips** and **C. pini**, causing blue stain, a phenomenon closely associated with stoppage of conduction and drying of wood. In the Southern Appalachian region, pure pine stands are more susceptible than pines mixed with hardwoods. Beetle damage in these stands hastens the dominance of climax oak-hickory types.

Low winter temperatures result in death of many of the over-wintering brood, 10°F causing almost complete mortality of the brood in the moist phloem, 0°F is fatal to all stages except the egg, and —5°F is usually fatal to eggs (Beal, 1933). As most of these insects overwinter as larvae, there is a high mortality of the brood when the temperatures drop to between

10 and 15°F. Low temperature for a single night is probably as effective as longer cold periods. Larvae in the phloem are more likely to die in cold weather than those in the outer bark due to the greater amount of water —and its temperature conductivity—in the inner zone (Beal, 1927).

High summer temperatures do not affect southern pine beetles in standing trees. Beneath the bark of felled logs, on the other hand, high temperatures, reaching 112° F when air temperatures are between 70 and 80° F, kill insects (Beal, 1933).

Interestingly, woodpeckers, ardent foes of the southern pine beetle, are killed by ice storms in great numbers. This, and the high incidence of breakage by ice, are factors relating injuries by the beetle to ice storms.

### Control

It is practically impossible to save infected trees. To save other stems and to control outbreaks, currently infested trees are felled and the trunks and stumps sprayed with BHC. One-fourth percent gamma isomer in No. 2 fuel oil (1 part of the concentrate to 56 parts of oil by volume) is the most satisfactory formulation. Kowal (1960) suggests a ½ percent concentration for winter treatments in the mountains to provide for greater residual effect. Only dry bark should be treated, and it should be wetted until an excess runs off. Areas sprayed in the growing season should be checked every 3 weeks for 9 weeks after treatment. Bi-monthly examinations will suffice for winter treatments. There is no need to apply insecticide if many holes, like birdshot, occur through the bark and the needles have turned red. Beetles have left such trees.

In the late 1940's, orthodichlorobenzene dissolved in 4 to 6 parts of kerosene was recommended, but apparently there was little follow-up of its usefulness (Gerhart and Ahler, 1949). Cutting and exposing logs to the sun for 2 or 3 days may kill the brood in the trunk, but it is necessary to limb the trees and to turn the trunk once in order to expose all sides to the sun. Peeling and burning the bark may also retard outbreaks.

Although the initial selection of host trees by female beetles appears to be by random flight, the flying population is concentrated in killing numbers by an attractant which the female emits upon boring into the tree. As infestation moves from tree to tree, "trap spots" may prove useful, consisting of a circle of trees sprayed with BHC and lindane in oil or water around host trees. Beetles will concentrate in these spots; trees then can be chemically treated or harvested before beetles emerge (Gara, 1966; Gara, Vité, and Cramer, 1965).

### Nantucket Pine Tip Moth

Loblolly, shortleaf, Virginia, and slash pines are attacked by the Nantucket pine tip moth, the first two seriously. Longleaf and white pines are immune. The insect is particularly injurious to trees under 7 feet tall. The larvae bore into the buds and twig tips and sever conducting tissues which causes tips to die, leaving disintegrating spikes. Severe infestations may leave trees with a witches' broom-like appearance. Trees may be permanently deformed with crooks and forks or occasionally killed by repeated attacks. Reduction in height growth of up to ½ foot per year is not unusual with heavy infestation. Generally, trees outgrow infestation; but the senior author has observed terminal buds over 25 feet above the ground severely attacked. Trees on better sites suffer less tip moth damage than on poor sites, the former outgrowing the damage more rapidly. There is evidence that some strains may be immune to tip moth attack.

Adult moths are inconspicuous, with wing spans of 9 to 15 mm. Irregular brick-red and copper colored patches, separated by bands of gray scales, occur on the forewings. Eggs are elliptical, 0.85 mm long, opaque and whitish when laid, yellow to orange a few days later, and finally gray when ready to hatch. They are generally laid singly. Larvae are cream-colored caterpillars 1½ mm long. The head is black and the body is covered with minute hair. Prior to pupating, they are 8 mm long. Pupae, the over-wintering stage, are 6 mm long and light to dark brown. Adults emerge in the spring to deposit eggs 2 days later on old-growth needles, on developing buds, or in the axils of the needles and stem. Egg incubation in the spring extends over a 2- to 4-week period. The larvae chew their way out of the eggs and then construct delicate inconspicuous webs in the axils formed by developing needles and stems, from which they bore into needle sheaths to feed. Subsequently webs are spun between buds, or buds and needles, and the buds are consumed. Migration to other buds continues and more than one caterpillar may be found boring down the center of a young stem (Yates, 1960; SEFES, 1959).

Internal feeding begins following development of the third instar of the larvae. Earlier, larvae remain on the outside of branch tips, feeding on needles and succulent tissue of developing shoots, and constructing webs on the shoots.

In Oklahoma one year, moth emergence began in mid-March, reached its peak 3 days later, and continued for another 2½ weeks (Afanasiev and Fenton, 1947). The second emergence was in early June, the third in mid-July, and fourth for the season in early September. In the warmest climates, six generations might occur in a single year. Some damage was reported in October.

#### Control

Afanasiev and Fenton (1947) recommended thorough spraying of DDT timed to coincide with the emergence of first and second generations to protect the first flush of new growth. Yates (1960) reports BHC effective. Both chemicals must be applied two to four times per year.

Silvicultural recommendations to prevent serious infestations include planting on favorable sites, mixing with resistant species, planting under an overstory, or planting at close spacing; but the degree of effectiveness for any of these measures is debatable. In spite of the great number of known predators—birds and insects—and the high degree of parasitism, these agents do not appear to significantly affect tip moth populations nor to reduce subsequent injury.

### Wind Damage

In spite of the relatively deep tap root, strong winds following prolonged rainy spells which saturate the ground may uproot shortleaf pines.

The ratio of shortleaf pines to loblolly pines blown over in a southeastern Arkansas storm was 20:1, due to abnormally shallow tap roots formed by shortleaf pines in the silty loam surface soil and mottled silty clay subsoil at a depth of 10 inches. The stand was neither crowded nor suppressed (Grano, 1953). On such poorly drained sites, isolated seed trees should not be retained. As loblolly pine roots grow satisfactorily in these soils, seed trees of this species are preferred to shortleaf pine. Shortleaf pine plantations up to at least 10 years of age have withstood strong winds in the upper Piedmont, in contrast to loblolly and slash pines (Cockrell, 1936).

## Integrated Management

### Wildlife

Little is known about integration of wildlife and timber management in shortleaf pine forests. Sometimes, as in the Barrens of southern New Jersey, deer are too numerous and redistribution is necessary to avoid herd starvation and severe browsing of planted pines. Work conducted in East Texas shortleaf-loblolly pine-hardwood forests indicated that considerable deer forage can be produced in well-stocked stands not encumbered with a dense midstory of hardwoods (Schuster and Halls, 1962).

Quail and rabbits may be encouraged in the Barrens by placement of 25-foot cleared food lanes covering 12 to 15 percent of the area. The lanes should meander to provide the greatest perimeter of edge and to avoid cutting valuable trees. Deciduous trees in the woods bordering the food lanes are thinned to increase interspersion of birds and, at the same time, to favor pines over oaks. Fire safety strips 100 feet wide along roads to protect food lanes should be burned annually (Moore, 1940).

### Range

Only shortleaf pine forests in the Ozark and Ouachita mountains are intensively grazed. Total herbage production decreases as the timber stand density increases, so that stands with 50 trees per acre 3 inches or larger support six times as much herbage as areas with about 400 trees. (The non-commercial hardwood forests of post and blackjack oaks on southern and western exposures produce 50 percent more herbage than do the good white oak-black oak-hickory sites of northern and eastern slopes.) In contrast to Coastal Plain forest ranges, there are more weeds than grasses in these uplands, and only one-fourth of the herbage is palatable to cattle. Bluestem species provide 60 percent of the grass.

Burning increases herbage for all Ozark sites except those with well-stocked hardwood stands. But, due to drier conditions on southern and western aspects, prescribed fires are confined to these sites. In burned areas, as much as 60 percent of the forest floor may be exposed to bare rock in the spring following a fire in contrast to 20 percent for unburned areas where rocks are covered with litter. Under either condition, green vegetation covers less than 30 percent of the forest floor (Read, 1948, 1951). Prescribed burning is advocated to replace weeds by legumes but, ordinarily, forbs increase over grasses and thus temporarily decrease the amount of desirable forage.

Ozark Mountain woodland ranges are also improved by aerial application of silvicides. Control of hardwood brush is best on areas of low site index (Ray, 1958). (In sprayed scrub oak-hickory land, grasses increased from 560 to 870 pounds per acre the first and second years in contrast to 400 pounds per acre where not treated. Forbs were reduced to ⅓ their original dry weight the first year, but increased the second year 2½ times (Crawford, 1960).) Silvicide spraying was preferable to spring burning for more complete and permanent release of herbaceous vegetation, even though slight gains in herbage yields followed fire (Ehrenreich and Crosby, 1960). Five years after spraying, total herbage yield was 4½ times greater than on burned sites and 5½ times that of non-treated areas. Little bluestem grass increased from 50 to 70 pounds per acre on burned areas and to 800 pounds on areas treated with foliage sprays of 2,4,5-T in early June.

For medium- to well-stocked stands, an estimated grazing capacity is 10 to 40 acres per cow-month. In sparse forests, it is 6 acres per cow-month if unburned, and 4 acres if burned. This is in contrast with 2 acres per cow-month in open bluestem meadows.

**Watershed**

In plantations of the South Carolina Piedmont province, a 2-inch layer of undecomposed needle litter weighing over 4 tons per acre reduced raindrop impact appreciably. This litter layer, in the absence of humus, held from 0.01 to 0.09 inch of water after rain and, thereby, reduced erosion by providing time for infiltration to take place gradually. Saturated litter loses about three-fourths of its water during the first 4 days of drying, but does not come to equilibrium until the eleventh day (Metz, 1958). Under pine shade and litter, evaporation from the upper foot during spring and summer is two-thirds as much as from bare soil in the open. One-half of the evaporation from the upper 20 inches of soil under pines is likely to come from the upper 6 inches (Kittredge, 1954).

There are about 20,000 pounds per acre of litter under pines in old-fields when the weight has reached equilibrium at age 20 to 35. Conifer litter is several years behind broadleaf trees in accumulating (Auten, 1945). Shortleaf produced less litter than loblolly pine in a 4-year-old erosion-control planting in north Mississippi (Thames, 1962).

Destruction of humus exposes soil to the impact of raindrops. Where mor humus types are burned, particularly, this exposure is sufficient to seal pores and reduce infiltration to a negligible rate. Continual burning retards the formation of a desirable mull humus layer by eliminating litter that would in the course of time become incorporated with mineral soil. Fire may also significantly reduce populations of organic-decomposing fauna and flora living in the unincorporated litter of the forest floor. Even when fires are subsequently excluded, mull formation is retarded until the biologic complex is restored. Although occasional wild fires in Piedmont pine stands reduce growth, probably due to defoliation and cambial injury rather than to soil destruction (Coile, 1952), annual burning under severe conditions, no doubt, is deteriorating to soil water-holding properties.

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## APPENDIX

Common and scientific names of species mentioned in the text.

### Trees and Shrubs

| *Common name* | *Scientific name* |
|---|---|
| Dogwood, flowering | *Cornus florida* |
| Hickory | *Carya* spp. |
| Maple, red | *Acer rubrum* |
| Oak, black | *Quercus velutina* |
| blackjack | *Q. marilandica* |
| northern red | *Q. rubra* |
| post | *Q. stellata* |
| scarlet | *Q. coccinea* |
| southern red | *Q. falcata* |
| white | *Q. alba* |
| Persimmon, common | *Diospyros virginiana* |
| Pine, loblolly | *Pinus taeda* |
| longleaf | *P. palustris* |
| Monterey | *P. radiata* |
| pitch | *P. rigida* |
| shortleaf | *P. echinata* |
| slash | *P. elliottii* |
| Virginia | *P. virginiana* |
| Redbud, eastern | *Cercis canadensis* |
| Redcedar, eastern | *Juniperus virginiana* |
| Sassafras | *Sassafras albidum* |
| Sweetgum | *Liquidambar styraciflua* |
| Walnut, black | *Juglans nigra* |
| Yellow-poplar | *Liriodendron tulipifera* |

### Herbs and Vines

| | |
|---|---|
| Kudzu | *Pueraria thumbergiana* |
| Lespedeza | *Lespedeza* spp. |

### Grasses

| | |
|---|---|
| Broomsedge | *Andropogon virginicus* |
| Common Bermuda | *Cynodon dactylon* |
| Little bluestem | *Andropogon scoparius* |

### Insects

| | |
|---|---|
| Nantucket pine tip moth | *Rhyacionia frustrana* |
| Pine sawfly | *Neodiprion* spp. |
| Southern pine beetle | *Dendroctonus frontalis* |

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